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PROJECT ARTEMIS ACOUSTIC SOURCE

Description and Characteristics of the Facility as Installed on the USNS MISSION CAPISTRANO (T-AG 162)

[UNCLASSIFIED TITLE]

A. T. McClinton

SOUND DIVISION

8 March 1962

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U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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A. T. McClinton

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ABSTRACT

This report describes an acoustic source developed for Project ARTEMIS. A T-2 class U. S. Navy tanker has been modified to contain the entire facility consisting of source of electric power, amplifiers, control and instrumentation system, transducer array, and array and cable handling machinery. All components of the system have been tested and found to meet design requirements. Acoustic interactions in the multi-element transducer array have restricted the permissible acoustic radiated power until the associated velocity anomalies can be eliminated or reduced. Several promising methods are being investigated.

PROBLEM AUTHORIZATION

ONR RF 001-03-03
NRL Problem Number 55S02-11

PROBLEM STATUS

This is an interim report on this project; work is continuing.

V. HIGH POWER ACOUSTIC SOURCE

by

Mr. A. T. McClinton
Naval Research Laboratory

REQUIREMENTS

The general requirements for the acoustic source were formulated during the early stages of investigation of equipment needs for conducting the experimental studies required in support of Project ARTEMIS. The acoustic requirements which have remained unchanged throughout the development of the source are listed below.

Frequency	400 cycles per second
Power	1000 kilowatts acoustic
Beam Pattern	
Vertical	12.5 degrees (-3 db points)
Horizontal	20 degrees (-3 db points)
Source Level	152 decibels
Pulse Length	10 milliseconds to 60 seconds

In the earlier stages of the program development, it was conceived that the transducer would be fixed to the bottom in a water depth of 1200 feet and that the acoustic axis would be tilted 11 degrees above the horizontal. Many sites were investigated to determine their suitability for this installation. Facets of primary importance were the bottom slope, the proximity of the 1200 foot contour line to a land mass on which the transmitter and other related equipment could be located, and propagation characteristics. It was not possible to find a site that satisfied these requirements and acoustic transmission require-

ments imposed by experiments which were contemplated. The investigation concluded with the decision to place the source at Plantagenet Bank southwest of Bermuda.

Due to the 25 mile distance from Plantagenet Bank to Bermuda, it was not economically feasible to place the transmitter and related equipment on the island of Bermuda. Two alternative systems were investigated; namely, the use of a tower on Plantagenet Bank in a water depth of 180 feet and the use of ship-installed equipment. The ship installation was concluded to be the more promising approach since it offered the potential of a mobile source in the early stages of the acoustic transmission studies. This would then be followed by fixing of the transducer to the bottom, operating as a fixed source with the ship moored in a suitable moor on Plantagenet Bank and supplying power to the transducer from that point. It was this system that established the requirement for the source and which will be described.

SYSTEM DESIGN AND INSTALLATION

The acoustic source developed in accordance with the requirements set forth above is composed of all of the equipment from the source of electrical power to the transducer In addition to this, it consists of the winches, cable machinery and other pertinent equipment necessary to lower and raise a 700,000 pound transducer array to a depth of 1200 feet and to supply the electrical power to the device at this depth. A system block diagram is shown in Figure 1. It is to be noted that this system consists of three basic parts, as follows:

1. The fixed shipboard equipment consisting of source of power, amplifier and controls,

2. The submarine cables, and

3. The transducer array consisting of the transducer, electrical components, controls and instrumentation.

The ship selected for installation of this equipment was formerly a T2-SE-A2 class tanker. This provided the necessary space for installation of the components and also afforded the structural suitability for a large center well through which the transducer array could be lowered. The location of the component parts of the project equipment is shown on the arrangement plan in Figure 2. The gas turbine generator is located aft in what were formerly center tanks 9 and 8. The major switch gear associated with the power distribution and control center for the turbine is located in this area on a platform overlooking the gas turbine generator. This arrangement places all of the power generating equipment in the after part of the ship, simplifying ease of operation, maintenance and distribution of power.

Handling of the transducer array is through a well cut from the main deck to the keel in part of the area formerly used for center tanks 7 and 6. This well provides an access area 30 feet by 48 feet for stowing, lowering and raising of the array.

The electronic amplifier, project control center and other related facilities are located forward of the array. These are in what were formerly center tanks 5 and 4. Immediately forward of these compartments is the

electrical cable machinery for handling the electric submarine cables to the transducer array.

This installation, made on the USNS MISSION CAPISTRANO (T-AG 162), is shown in Figure 3. The view is up to date except that the array now contains 75 percent of the transducers, whereas at the time the picture was taken only ten percent were in place. Evident in this photograph are the helicopter platform located forward and a pipe rack just aft. The pipe rack is part of the equipment required for fixing the array to the bottom when it is used as a fixed source.

The gas turbine generator which furnishes power to the electronic amplifiers is shown in the artist's conception of Figure 4 and on the factory floor in Figure 5. It is rated 8000 kilowatts at 4160 volts, three phase, 60 cycles per second. Special provisions have been made in the control systems to provide precise frequency and voltage control and to minimize the thermal shock on the gas turbine due to the step load application and removal. These controls are capable of accepting a transient step application or removal of load from 800 kilowatts base load to 8000 kilowatts full load. Under this condition the transient voltage variation is less than two percent and in frequency variation is less than one percent. Furthermore, the transient temperature variation of the gas turbine blades will not be detrimental to turbine life.

The electronic amplifiers, along with switch gear, matching transformer, test load and related instrumentation, are shown in the artist's con-

ception of Figure 6 Four amplifiers (Figure 7), each rated at 1300 kilowatts, are installed in this area. These units may be operated singly or in parallel to give a maximum power of 5200 kilowatts. A central control panel which permits operation and monitoring of the amplifiers and transducer array is shown in Figure 8. A master programmer is also located in this control center to program the time sequence of events pertaining to operation of the gas turbine generator, amplifiers and related instrumention.

The transducer array consists of 1440 transducer elements, associated electrical components, acoustic pressure release system and pressure compensation. This is mounted on an array structure that is 44-1/2 feet wide by 54 feet high by 22-1/2 feet deep at the lower end The radiating face is tilted upward at an 11 degree angle with the vertical. A tripod structure supporting the hydrophones associated with the instrumentation system causes an overall array height of 75-1/2 feet Weight of the completed array will be 690, 000 pounds This array, with 75 percent of the elements in place, is shown in Figure 9

The transducer element is an electromagnetic variable reluctance device approximately one foot cubed, weighing 160 pounds. These are assembled into modules of 72 elements arranged mechanically six elements wide by 12 elements high The modules are assembled on the array in four horizontal rows, each row consisting of five modules. The top row of modules has not been installed (Figure 9)

Electrical equipment, required to match the transducer impedance to the submarine cable voltage, capacitors to compensate for the load reactance, and rectifiers to provide the dc polarization required for the transducer elements are installed in electrical component tanks on the bottom of the array structure. In addition to this, measurement and control functions are provided. Array orientation instrumentation provides depth, azimuth, level and cross level information. An assembly of four hydrophones positioned in three coordinate axes on the top of the array structure provides a means for determining array orientation relative to an acoustic monitoring hydrophone.

Special machinery to handle the array structure, electrical cables and facilities for stowage of the array system were developed and installed on the ship. A composite arrangement of the machinery is shown in Figure 10. One of the two array winches is shown in Figure 11, and one of the three electric cable machines is shown in Figure 12. The electric cable machines permit continuous supply of power from the amplifiers to the array without the use of slip rings or connectors.

The termination of the wire rope and of the electric cables at the array are shown in Figure 13. The array is supported by two two-part lines consisting of 2-3/4 inch wire rope. The rope passes over the live sheave through a cable guide at the top of the array structure, around the sheave on the array, up through another cable guide to the ship where the bitter end is secured on a bitter end sheave. A roller path guide positioned at the center

of roll supports the 2-3/4 inch wire rope at this point to minimize the translation forces imparted to the array due to ship's motion. The electrical cables enter the well over roller path guides on the port bulkhead of the array well and into the array structure on the rear face through appropriate cable bells.

The array stowage system, shown in Figures 13 and 14, provides for guiding the array into the array well, and for securing it while the ship is transiting between areas. The array is guided into the ship by means of six guide shoes (three forward and three aft) on the array and two guide tracks located on the fore and aft bulkheads of the array well. These guide tracks consist of two sections: an upper section which is fixed to the ship and a lower section which is pivoted at deck level and shock mounted near the bottom to minimize shock on the array structure as it enters the well. The lower end of this bottom section is flared fore and aft and athwartships to accommodate the effect of roll and pitch as the array enters the tracks.

The array is secured in its stowed position by means of array hangers shown in Figure 13 and the stabilizing mechanism shown in Figure 14. The latter consists of an upper stabilizing assembly on the port side and two lower stabilizing assemblies on the starboard side. While in the stowed position, these stabilizing struts prevent motion of the array structure in the fore and aft and thwartship directions. The weight of the array is carried by two array support hangers, one located on the forward bulkhead and one on the after bulkhead. Thus, the entire array structure is supported in the ship independently of the wire rope.

A door was provided on the bottom of the ship (Figure 15) to close the array well when the array is in the stowed position. This door may be rolled fore and aft on a pair of tracks which are located on the port and starboard sides of the ship. Wire rope passing from the forward corners of the door to the main deck and thence to a winch is used to open the door. A similar arrangement of wire rope secured to the after end of the door is used to close the door. This door does not seal the well. However, it does prevent surging of water in the well while the ship is underway, thus preventing damage to the components in the array.

A central control station is provided on the after part of the deckhouse to overlook the array well (Figure 16). Located within this array control station are the controls for the two array winches, shown on the left, and the controls for the three electric cable machines, shown on right. The necessary instrumentation for operation of the array handling system is provided in the panels above the controls.

Provisions have been made for holding ship's heading and position while at sea. A 500 horsepower electric motor-driven propulsion unit has been installed in a bow tunnel to provide athwartship thrust. This will permit control of the ship's heading and thus orientation of the array. In order to hold the ship's position fixed relative to the bottom, a deep sea anchor system has also been installed. Suitable anchors and 30,000 feet of two-inch diameter polypropylene line are provided for mooring in water depths to be encountered between Bermuda and Eleuthera.

SYSTEM PERFORMANCE AND CHARACTERISTICS

The array handling system, consisting of winches, cable machinery, instrumentation and controls, performed satisfactorily in lowering the array to 1250 foot depths. This depth was achieved during the first test with the array system and has been used repeatedly since then. The array guide system has also performed satisfactorily throughout the operation with ship motion as high as ten degree roll and three degree pitch when the array entered the well. Difficulty was experienced with the array securing system in heavy seas. The basic design of the stabilizer was found unsatisfactory for the dynamic loads imposed by ship's roll and pitch. A new design was made and installed to meet the severe requirements imposed by the ship motion. The redesigned system has proven satisfactory to securely fix the array in the stowed position during January and February operations.

The individual components of the 400 cycles per second power system have been tested to full capacity and found satisfactory. System tests of this equipment have been completed with 3900 kilowatts of 400 cps power into the test load. Under these conditions, it was found that the system met all of the requirements.

The electrical system installed in the component tanks on the array structure has performed satisfactorily electrically. However, mechanical difficulties were experienced in the first operation with this equipment. A pressure compensation system is provided with these tanks in order to equalize

the internal pressure with the external pressure as the array is lowered to depth Due to an error in oil filling, all of the air was not removed. In the presence of air it is impossible for this pressure compensation system to maintain equalization of pressure. Upon correction of this deficiency, the entire structure has been lowered to 1200 feet and found to perform satisfactorily mechanically as well as electrically.

Experimental data has been obtained on the acoustic performance of the transducer elements and the transducer array. Tests on the elements have revealed that they meet all of the requirements of the specification. Tests on the array have been made with two modules and with 15 modules; that is, with an array one wave length square and an array 2-1/2 wave lengths by three wave lengths It was determined from these tests that the resonant frequency is 400 cps, efficiency is above 50 percent and bandwidth is 100 cps measured at the minus three decibel level (Figure 14). The current response obtained on the 15 module array is illustrated in Figure 18.

It was observed early in the testing program that mechanical failures were occurring of springs in the transducer elements. These failures consisted of breakage of one or more of the springs which support the internal mass. Since tests on individual elements revealed that they had met all of the requirements imposed by the specification and life tests of the springs indicated that they should be satisfactory, it was necessary to carry out a more extensive program of instrumentation of the array to ascertain the cause of these failures.

The instrumentation employed was accelerometers mounted on the radiating face of the transducer element, a special transducer element which was in-instrumented with internal accelerometers to determine the relative motion of the internal and external mass, and electric current sensors.

The data from these experiments reveal that a non-uniform displacement existed across the face of this multi-element array. Furthermore, it was observed that the radiating faces of the elements were out of phase with each other by varying amounts. This displacement or velocity anomaly also was found to be frequency dependent. A typical curve showing transducer displacement as a function of frequency is shown in Figure 19. All element positions in the array showed this type of characteristic except that peak amplitudes and the frequencies at which these occur are different.

The dependence of transducer element displacement on position in the array is shown for two rows of elements and one column of elements in Figure 20. For convenience of identification the array was divided into 36 horizontal rows starting with number one at the top and 30 vertical columns starting with number one at the left. The elements in each row or column are numbered consecutively, starting with one at the top and left respectively. Thus, row one is at the top of the array, row 18 is at the center and column 15 is at the center.

It will be observed that the variation in displacement is over four to one under the best conditions shown in Figure 20; that is, at 400 cps.

On the other hand, the variation is over ten to one at 430 cps. Similar dependence of phase angle of the elements displacement is evidenced from Figure 21. This data, which is the phase angle corresponding to the displacement data of Figure 20, shows that adjacent elements are vibrating as much as 110 degrees out of phase. Data obtained at other frequencies revealed that adjacent elements were 180 degrees out of phase. Under this condition, one element would be taking power from adjacent elements.

A mean displacement curve was computed from all of the displacement data in order that a percent rho c loading curve could be computed. The results are shown in Figure 22. It will be observed that the best loading was 0.5 rho c with the poorest being 0.3 rho c. Although the significance of a mean displacement curve and the associated percent rho c loading obtained for an array having such large variation in displacement magnitude and phase is questionable, nevertheless it does reveal in conventional terms the behavior characteristics of this multi-element array.

The curves of mean phase angle and deviation from the mean phase angle are shown in Figure 23. The frequency dependence of the non-uniform displacement is also shown in Figure 24. These data reveal that an optimum frequency of operation exists. This optimum occurs at approximately 385 cps. The next choice of frequency is approximately 405 cps. Even at these better frequencies it should be observed that several elements had a displacement over three times the value required had the array exhibited uniform velocity and unity rho c loading.

It is this non-uniform velocity, which causes relatively large amplitude of a few elements in the array, that has led to element failure when the array is operated at higher power levels. Although average displacements and computed rho c loading indicate approximately 50 percent power reduction, the one element which displays the greatest displacement actually controls the maximum permissible power for the array of elements as presently installed.

In order to reduce the rear radiation, a pressure release system consisting of resonant tubes was installed. These tubes have been found to be very effective in reducing the baçk radiation, as evidenced by Figure 25. It will be noted that a front-to-back ratio of 17 db or better was observed over the frequency range from 350 to 450 cps. Unfortunately, fatigue failure of these tubes was experienced when attempts were made to operate at high powers. Therefore, measurements of the resonant tube displacement were made at the same time that the experimental data were acquired on the transducer elements. It was noted from these data that the maximum amplitudes of displacement along the length of each tube were in excess of the anticipated value for the drive level being employed. The frequency distribution of tube displacement is shown in Figure 26. Although the distribution at the high frequencies is not as pronounced as with the transducers, it was noted that significant variation in displacement existed on different parts of a given resonant tube as well as between different tubes in the array structure. In

any event, the magnitude of the displacement of the tube walls was in excess of the fatigue limits, necessitating a limitation of acoustic power and selection of the optimum operating frequency.

The optimum operating frequency for the resonant tubes determined from Figure 26 is approximately 405 cps. The second choice of frequency is 385 cps. Since the data and experience indicated that the first limiting component on maximum acoustic power was the resonant tube and the second was the transducer array, 405 cps has been selected as the operating frequency. The maximum acoustic power has been set at 137 db source level. This is a conservative figure in terms of operating experience and from computed values based on experimental data. However, it has been selected to assure no further damage to the resonant tubes and transducer elements. This provides a 137 db source while methods are being investigated to correct the unacceptable velocity distribution.

INVESTIGATION OF VELOCITY ANOMALY CORRECTION

An investigation is underway to determine corrective action that can be taken to permit operating the array at its full designed power. The experience of other activities, in this country and in the United Kingdom, has been evaluated in an effort to determine methods that might be employed to reduce the non-uniform displacement amplitude and phase. Some of these activities were found to be having similar difficulties with multi-element arrays composed of elements a fraction of a wave length in dimension.

The investigations of the velocity anomalies in the ARTEMIS acoustic source are being carried out with two programs at the Naval Research Laboratory. These consist of a theoretical study and an experimental study. The theoretical studies and experiences of others indicate that present difficulties can be overcome by using (a) larger elements and/or (b) passive electrical networks. The approach to the first consists of cementing a number of transducer elements together to form element subassemblies of one-quarter wave length and larger. The second approach requires a change in the external electrical connection of the elements. The elements on each module consist of 12 parallel groups of six elements connected in series. One series tuning condenser is used to correct for the transducer reactance of this group of 72 elements. The elements will be recommended in parallel with individual series-connected condensers used to provide electrical tuning.

This experimental effort is being conducted utilizing two modified modules giving an array of one wave length square. Within this array is one subassembly of 36 elements cemented together to provide a subassembly one-half wave length square. Two additional mechanical sub-assemblies of cemented elements are also provided, each of which has 12 transducer elements. These are each one-third wave length by one-quarter wave length. The remaining area in the area is filled with the standard transducer element. Means are also available for providing the passive electrical networks and

parallel connection of transducer elements to investigate the improvement possible with parallel operation as opposed to the present series-parallel operation. In the absence of transducer test facilities this experimental work is being carried out on the USS HUNTING (EAG 398) in the Chesapeake Bay. It is anticipated that the results will be available by the end of April. A future program of modification to the array installed on the USNS MISSION CAPISTRANO will depend on the outcome of these experimental and theoretical studies.

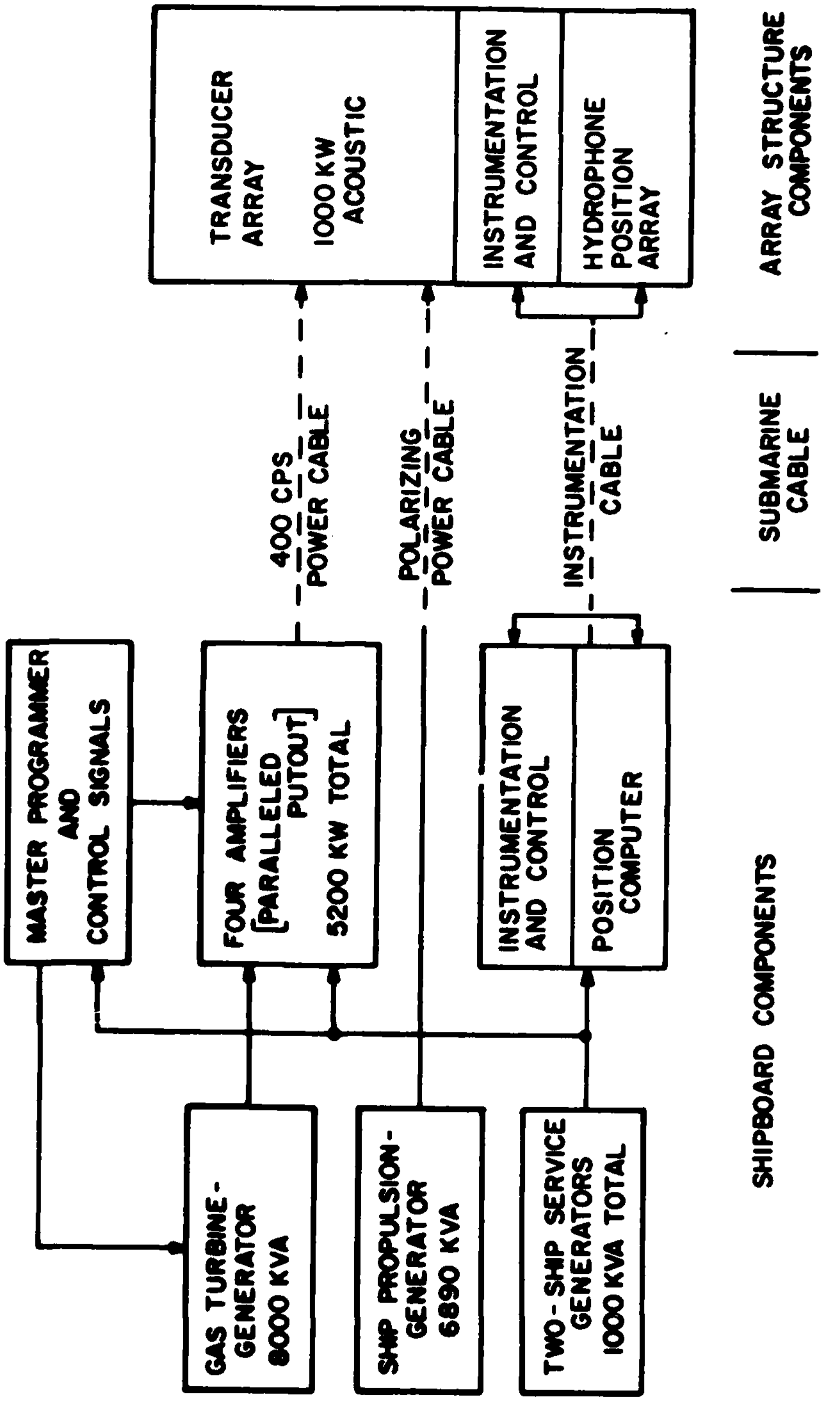

Figure 1 High Power Acoustic Source System Block Diagram

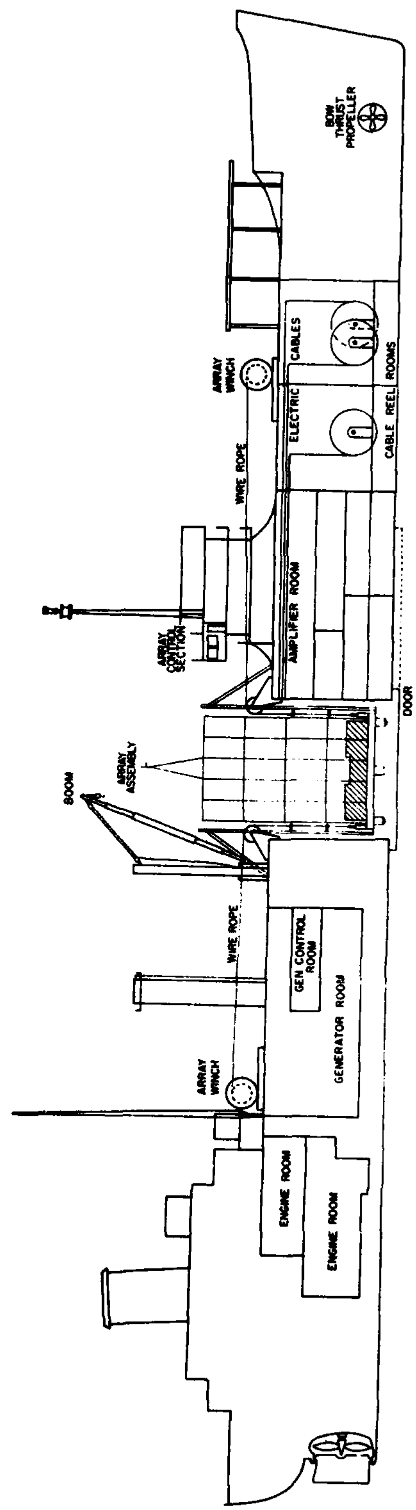

FIG. 2

EQUIPMENT ARRANGEMENT ON MISSION CAPISTRANO

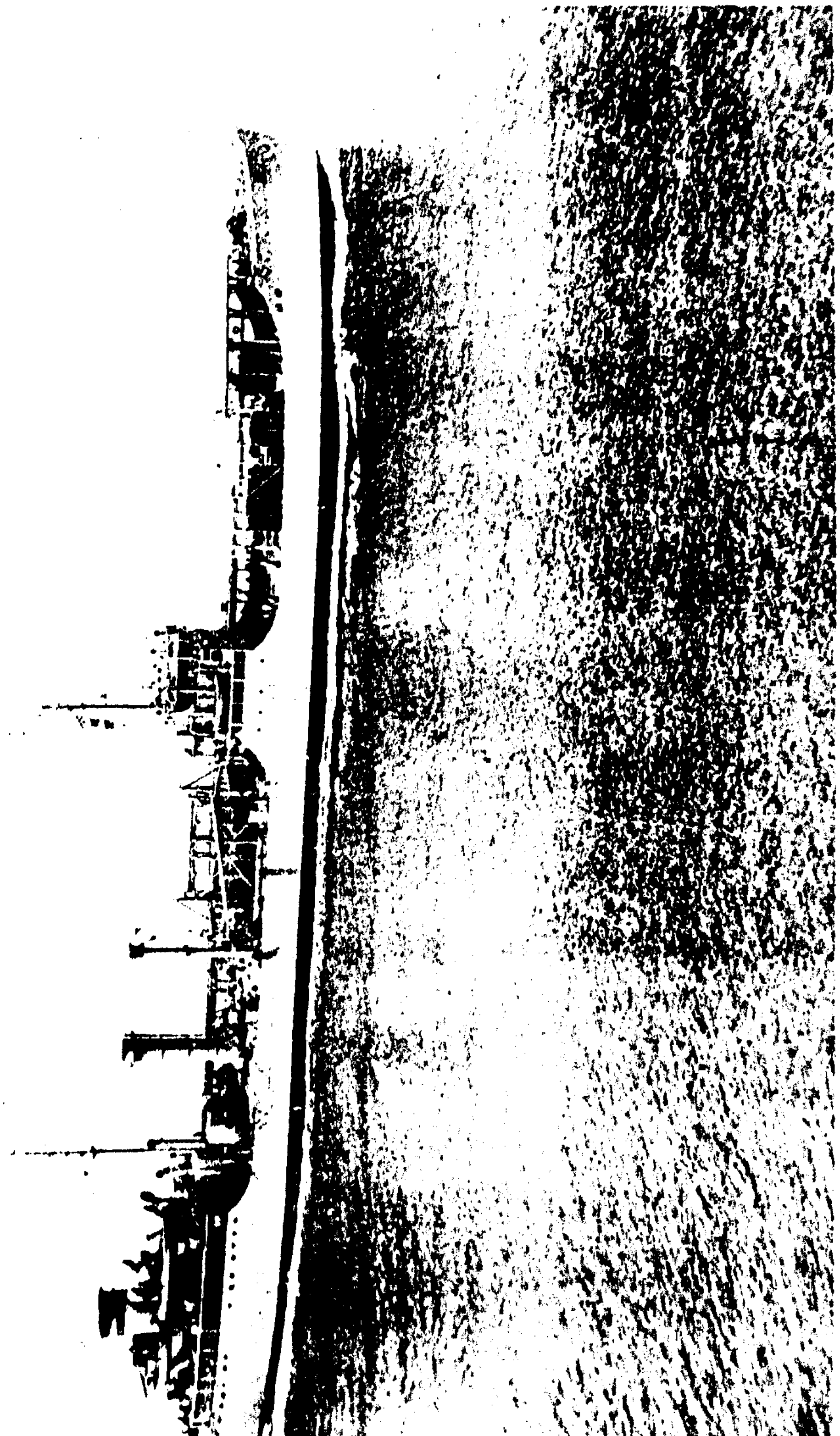

Figure 3 USNS MISSION CAPISTRANO after Modification

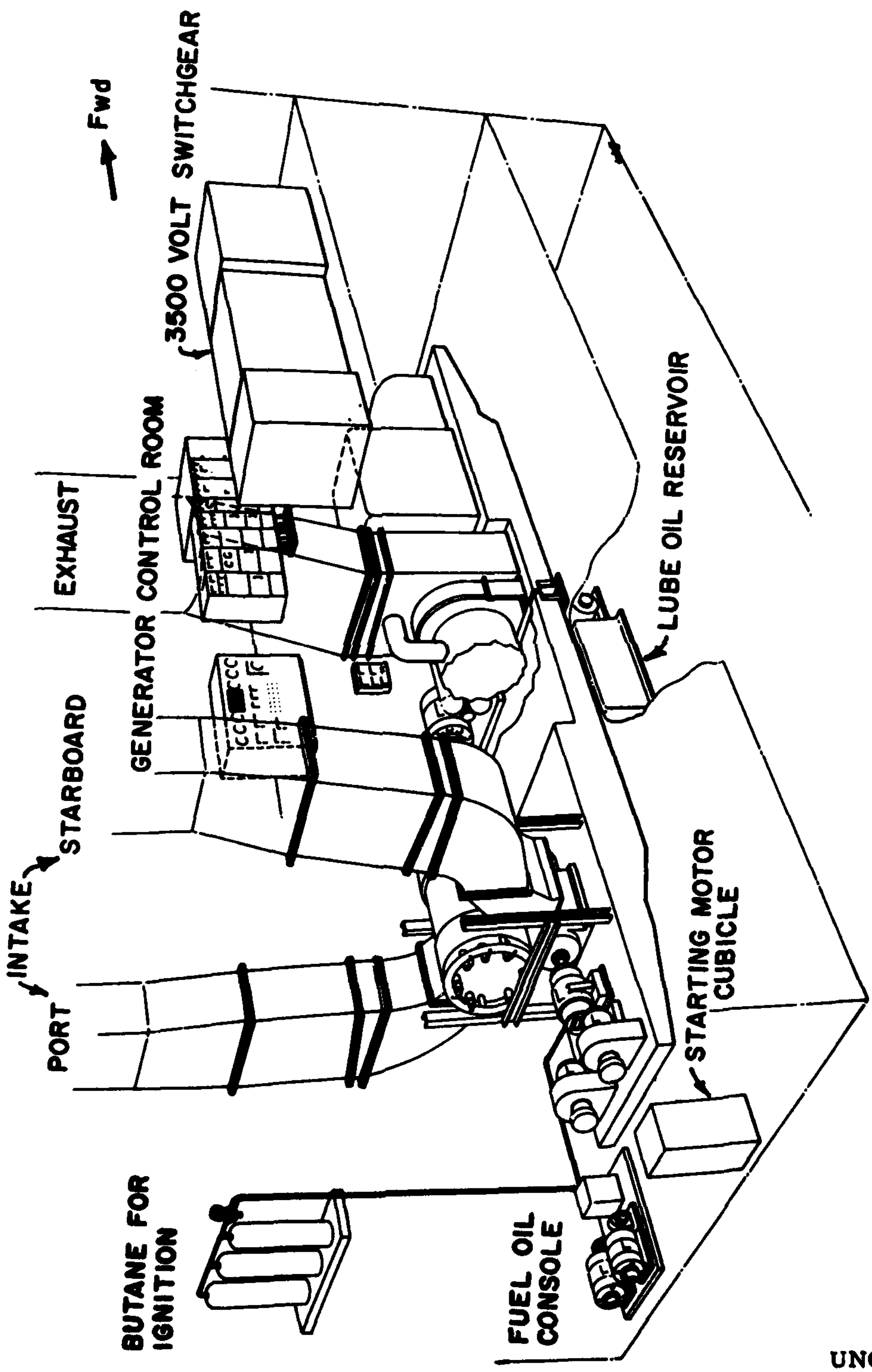

Figure 4 Gas Turbine Generator Installation

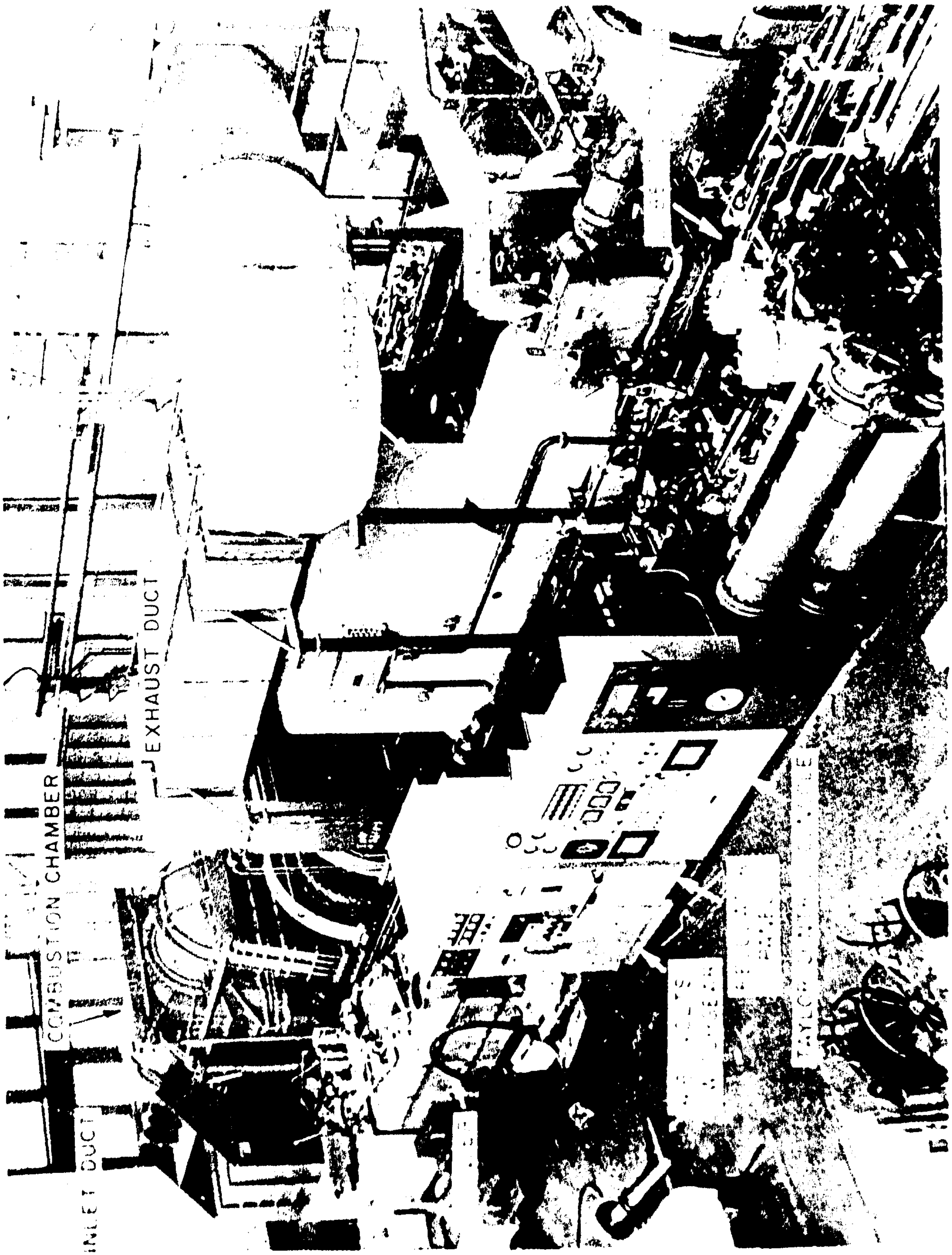

Figure 5 Gas Turbine Generator at Factory Test

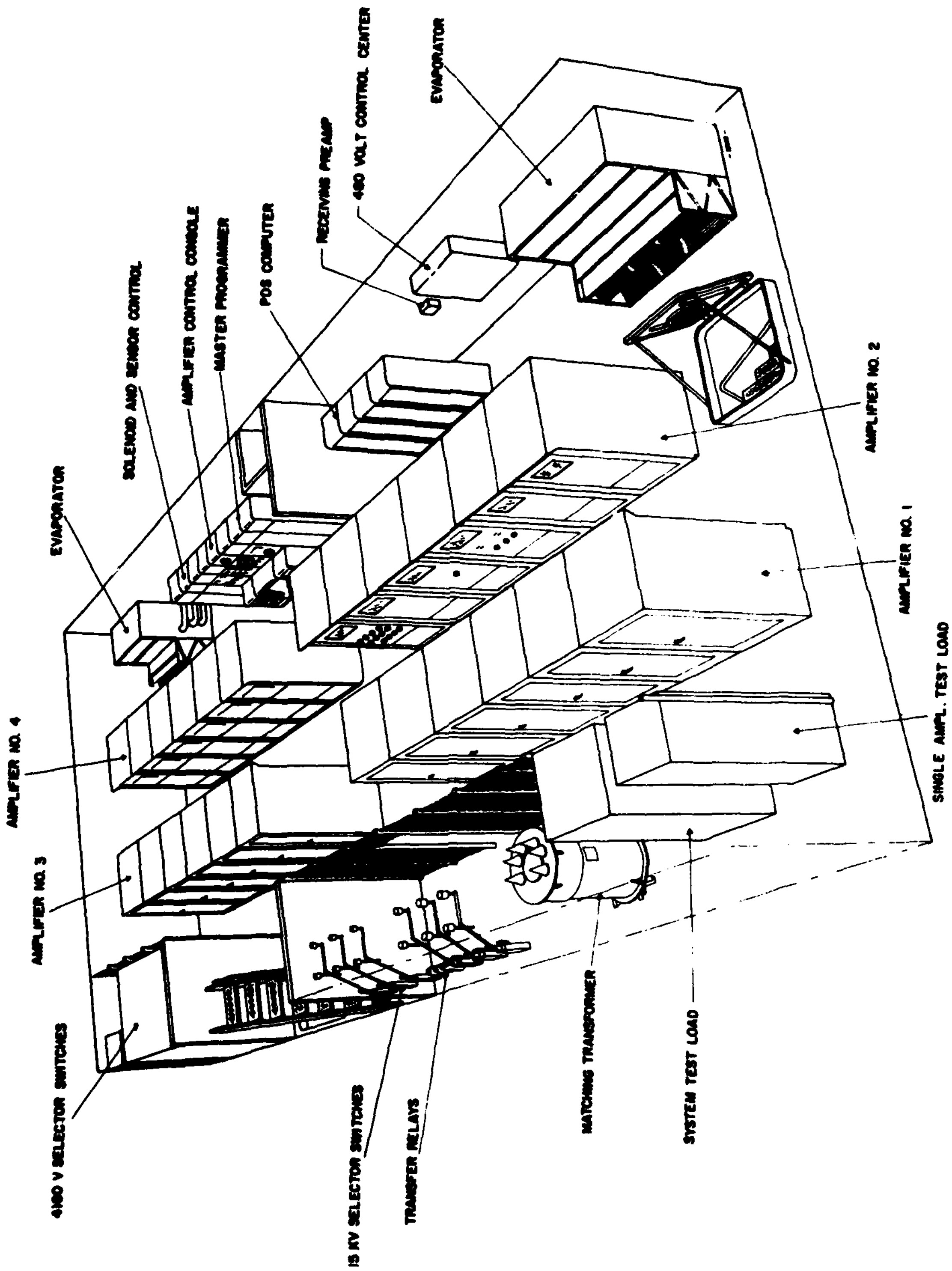

Fig. 6 - Amplifier room

Figure 7 Electronic Amplifiers

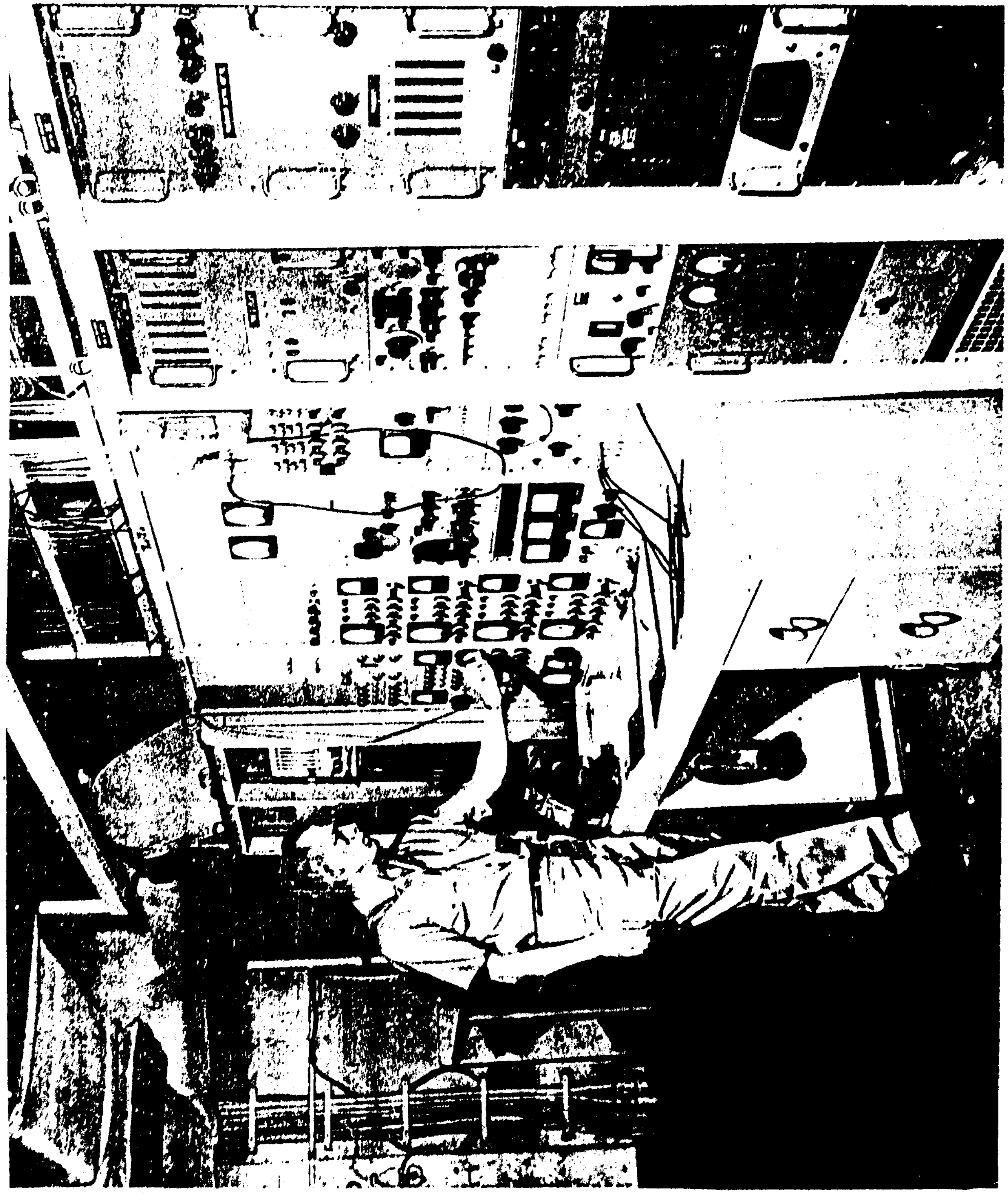

Figure 8 Amplifier Control Console

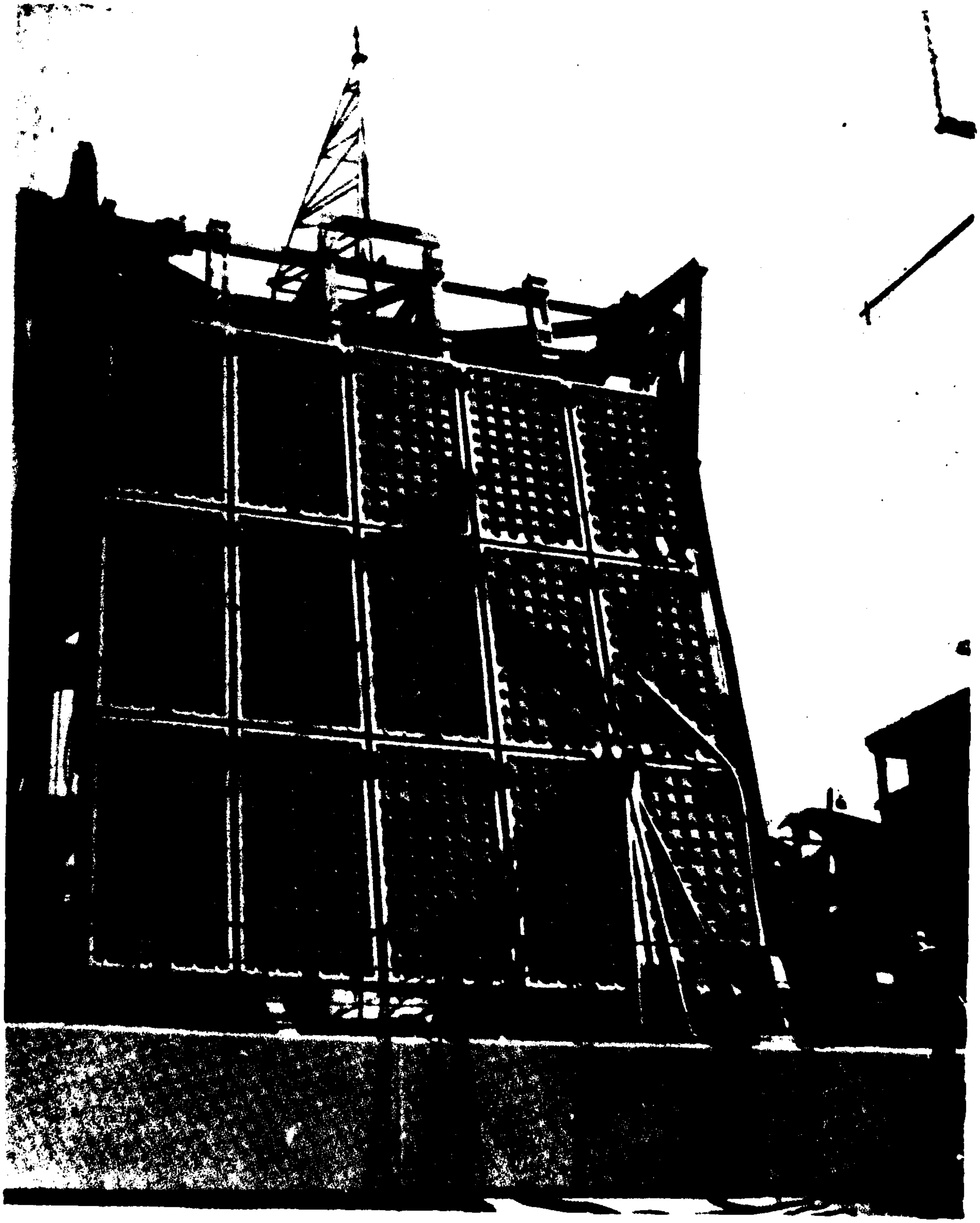

Figure 9 Array Installation of 15 Modules

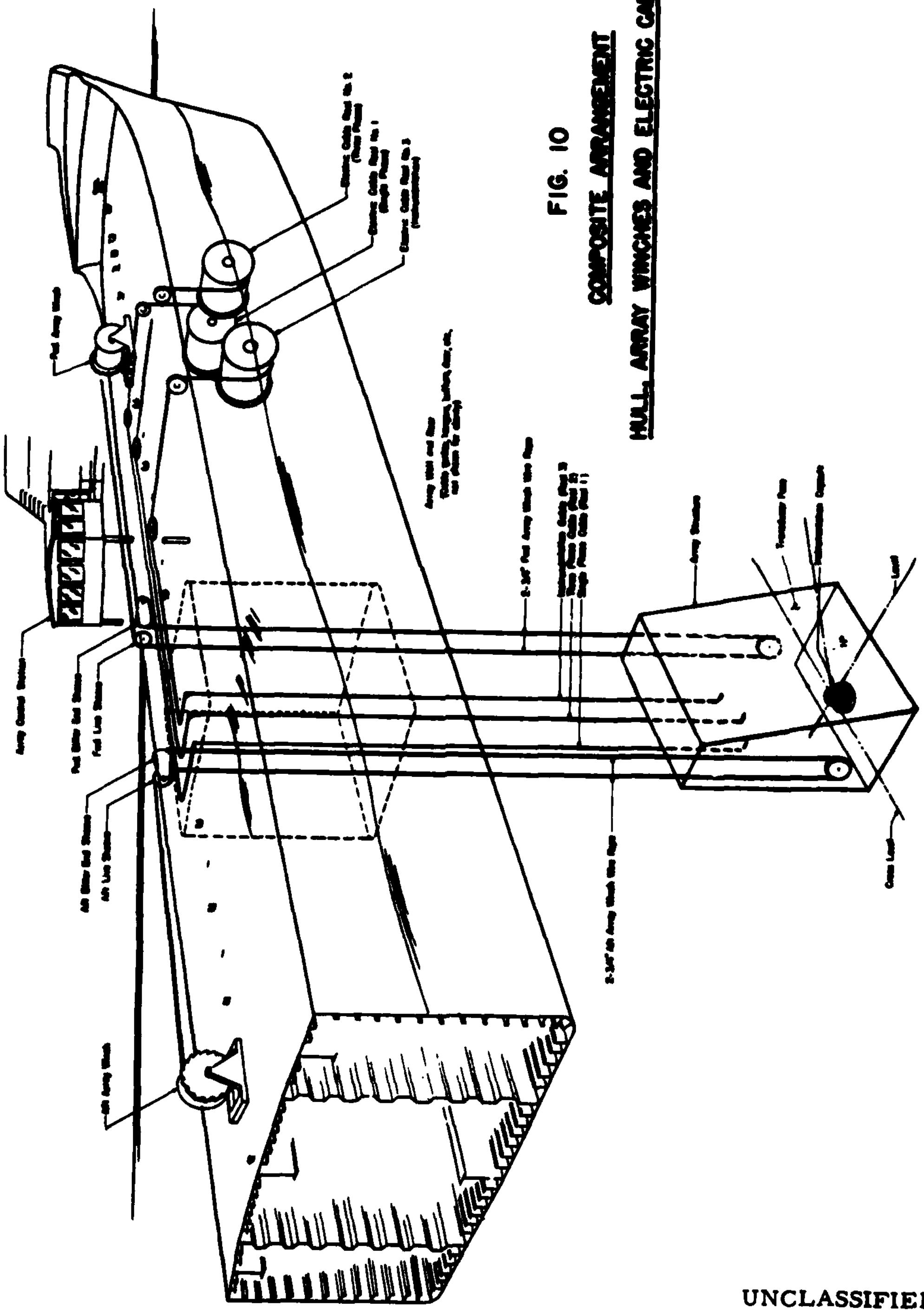

FIG. 10

COMPOSITE ARRANGEMENT

HULL, ARRAY WINCHES AND ELECTRIC CABLE REELS

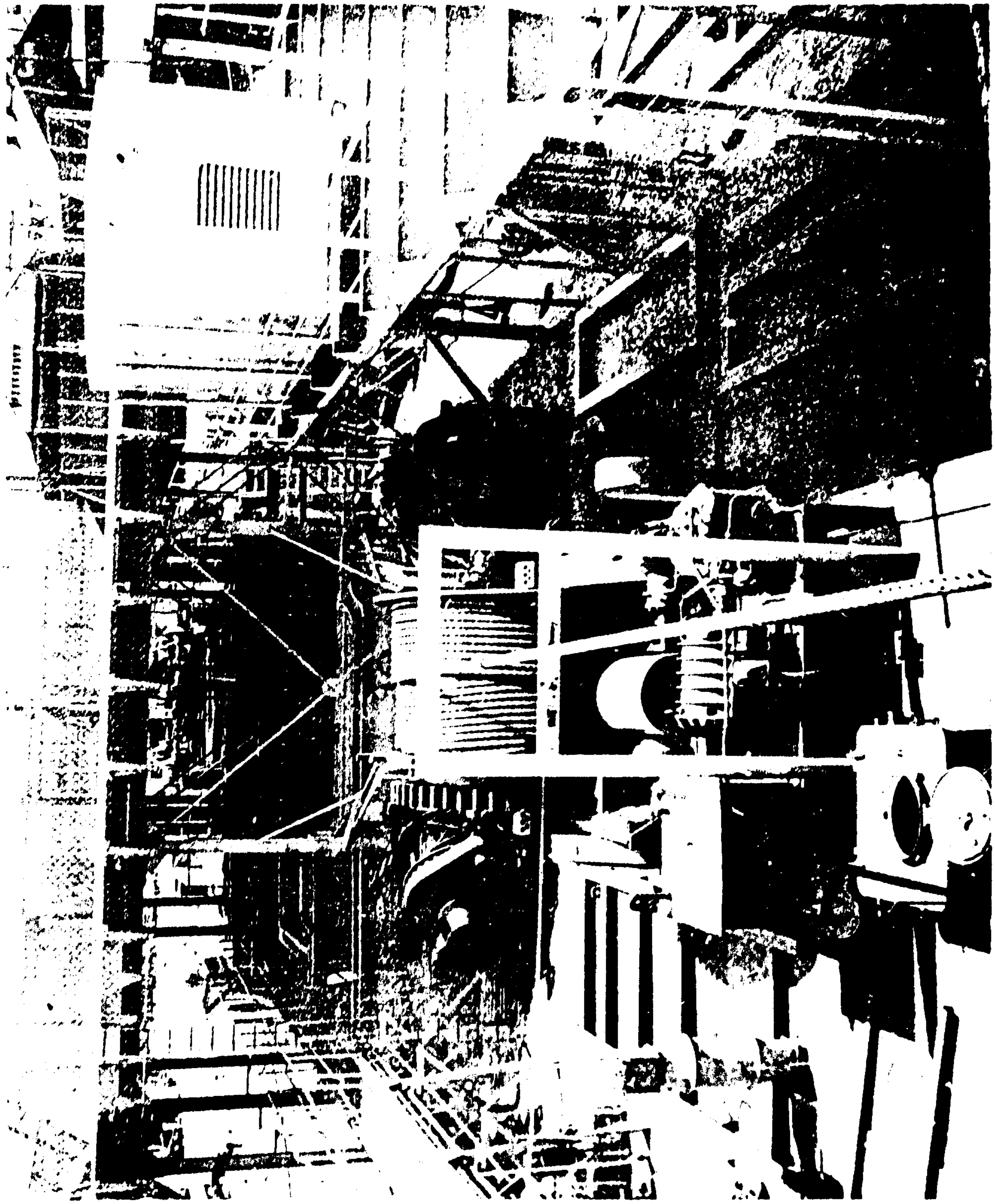

Figure 11   Winch Forward

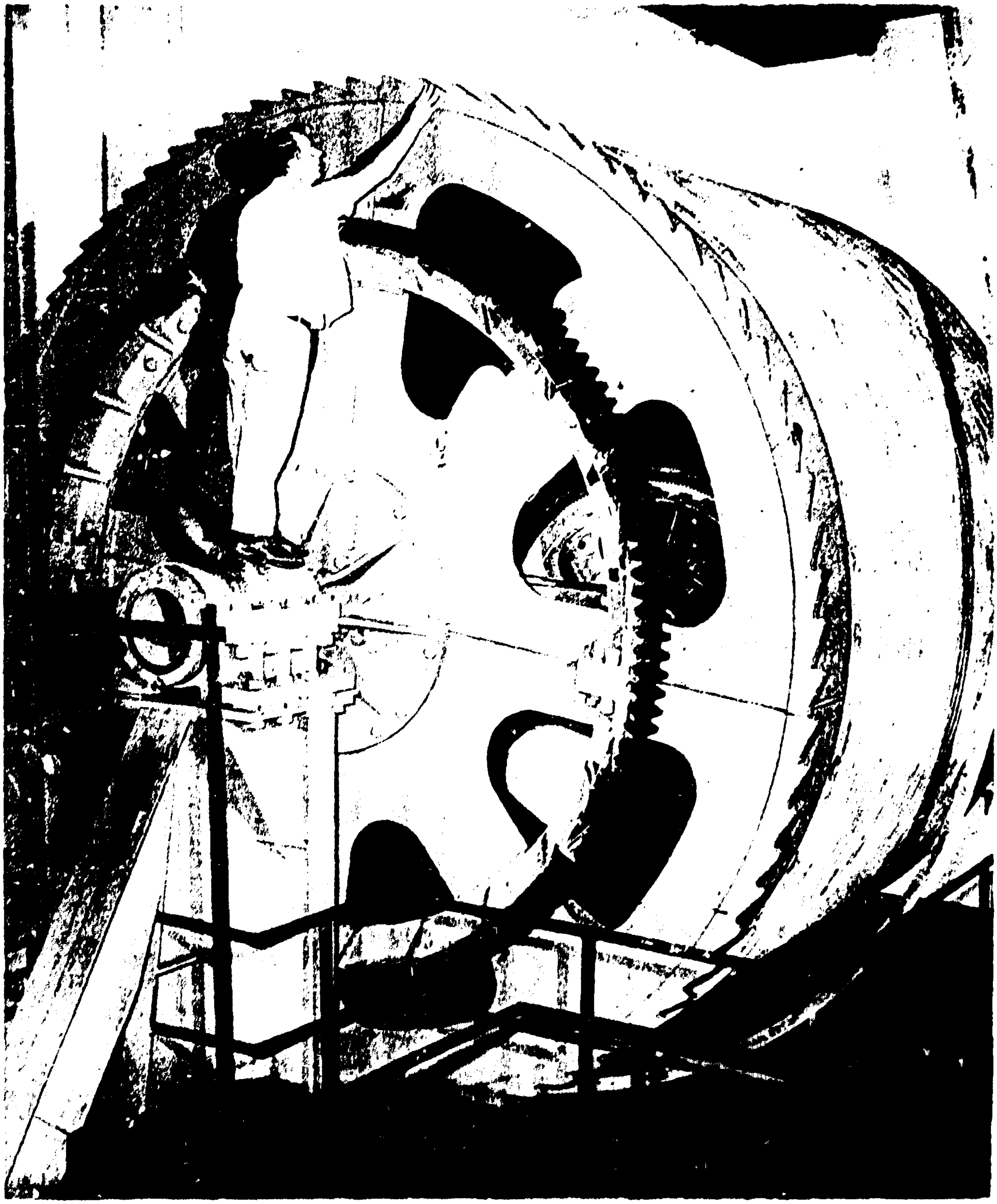

Figure 12 Electric Cable Machine

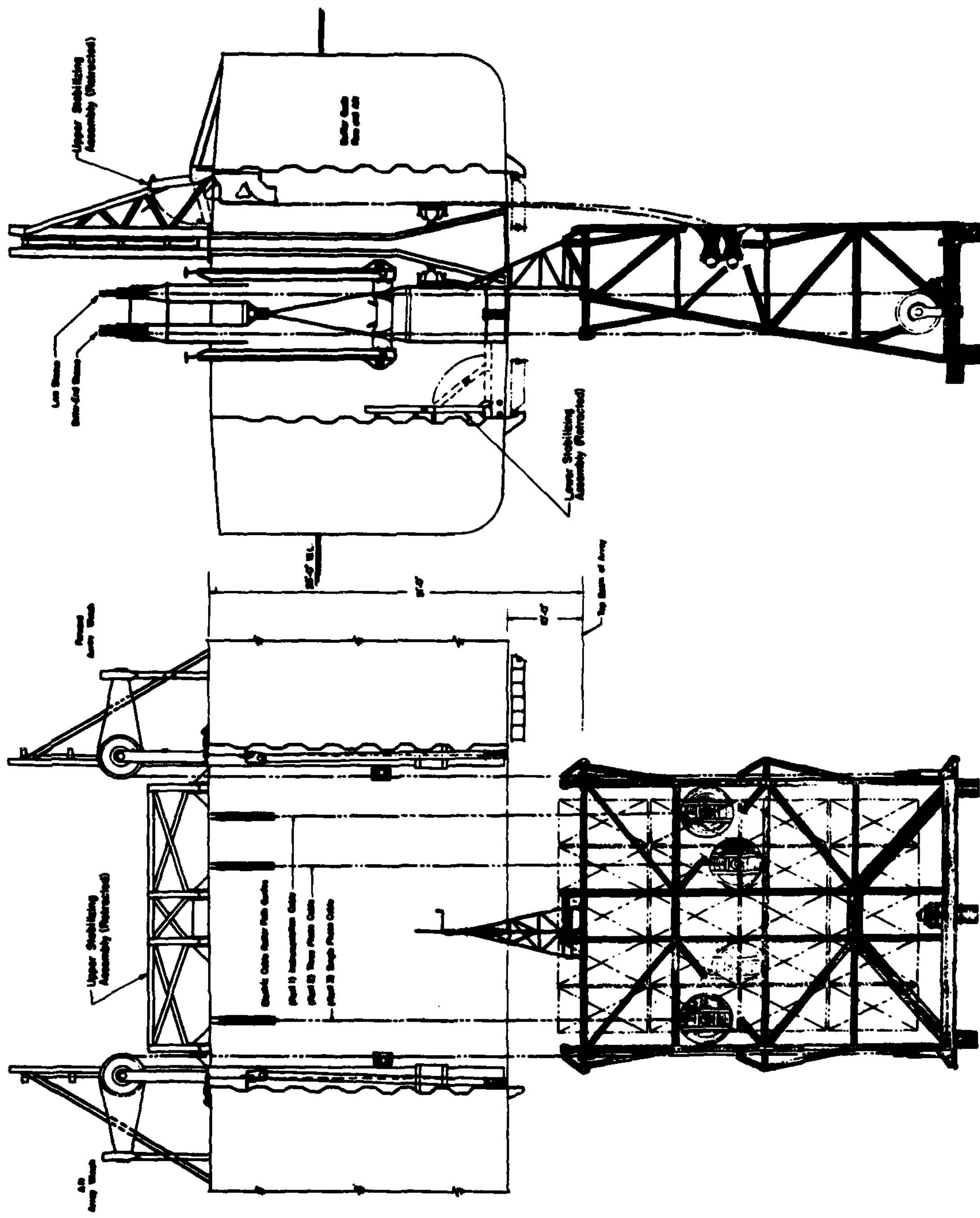

FIG. 13
ARRAY AND ARRAY STOWAGE SYSTEM

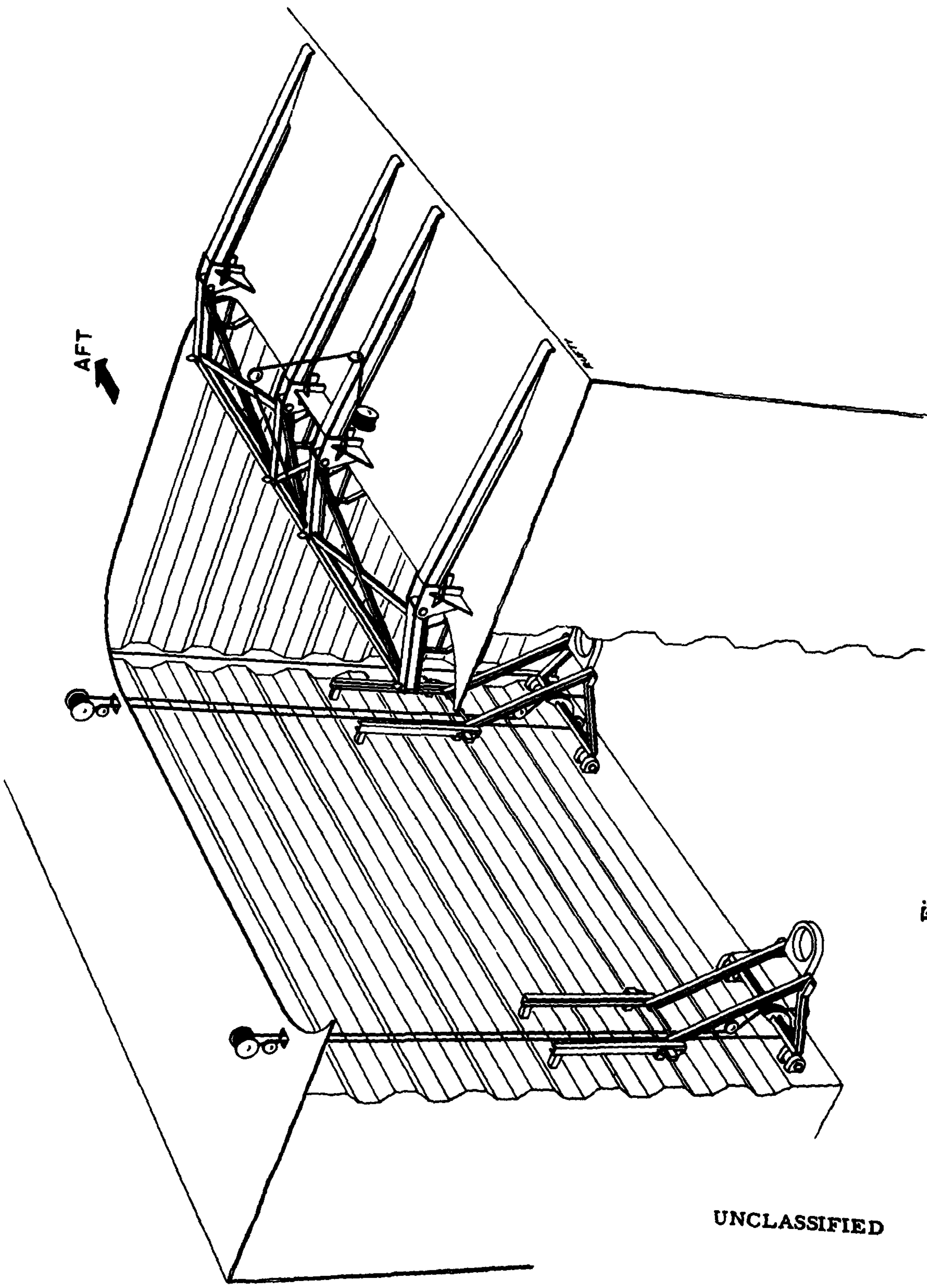

Figure 14   Array Stabilizing Mechanism

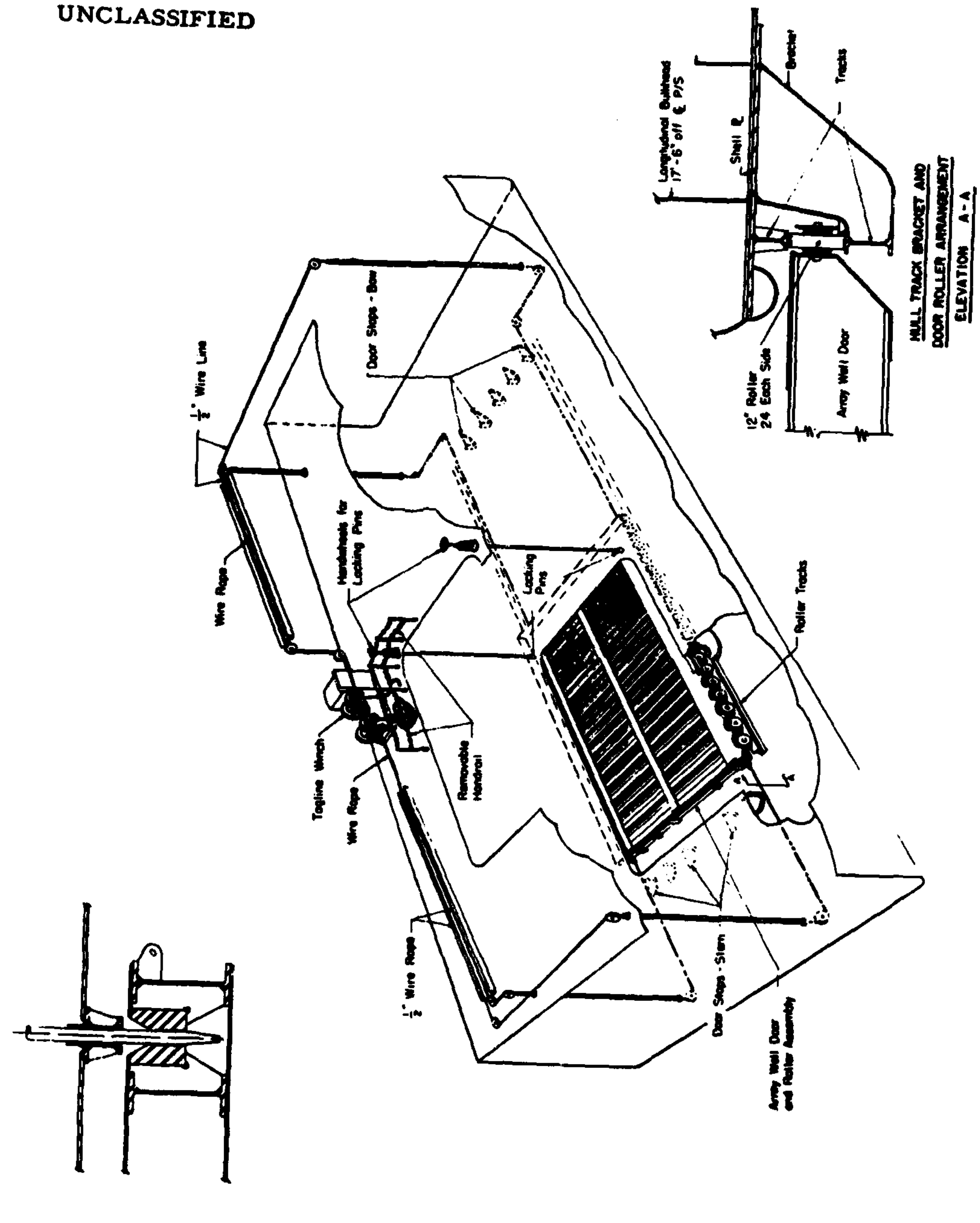

FIG. 15
ARRAY WELL DOOR

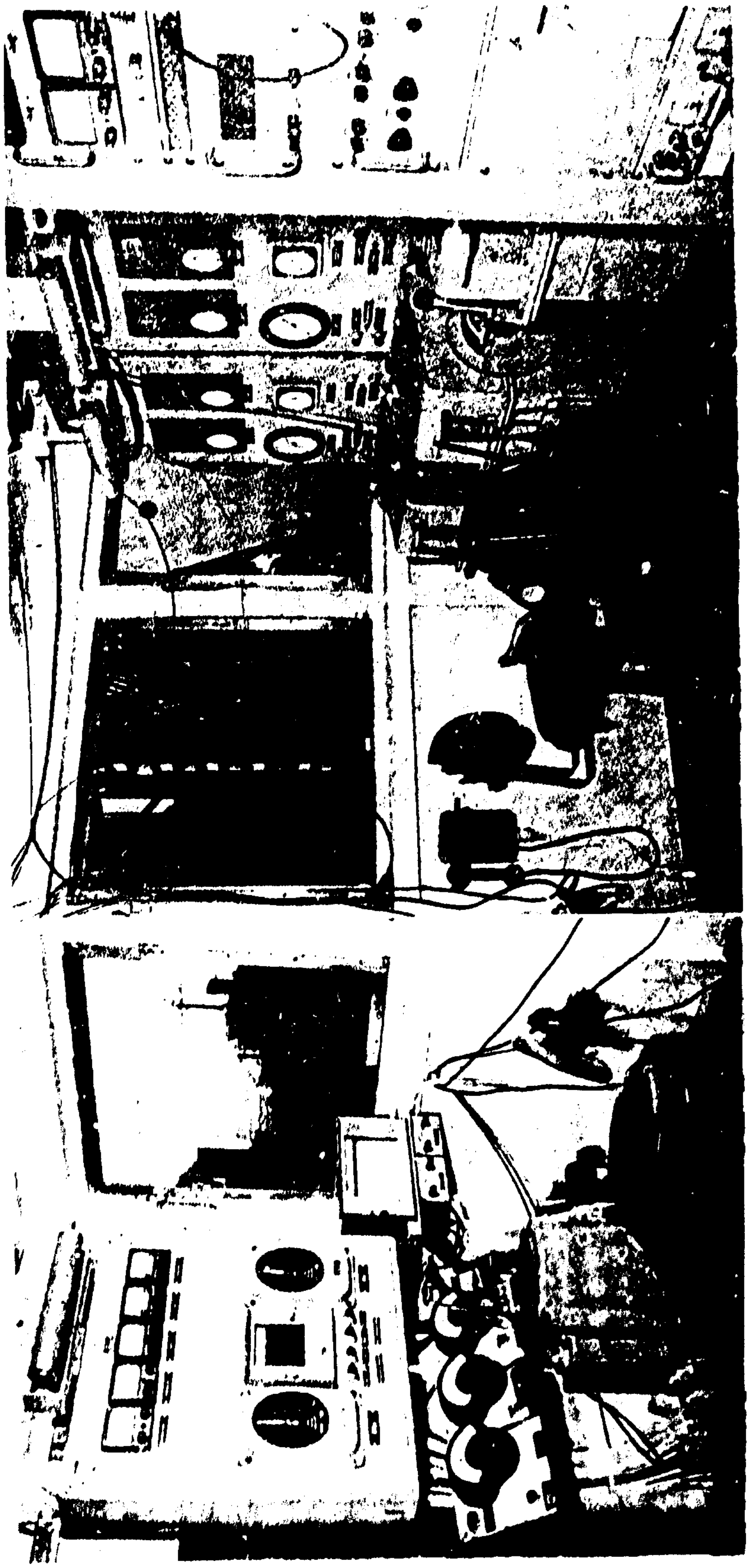

Figure 16 - Array Control Station

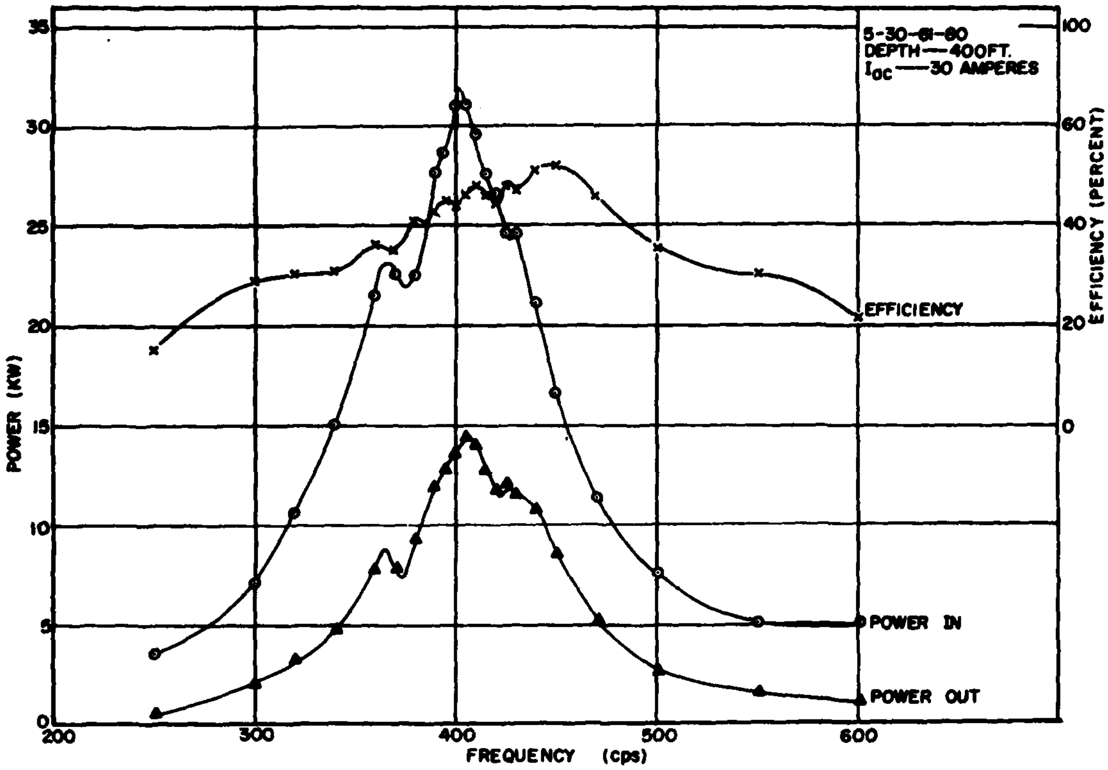

Figure 17 Efficiency Characteristics of Array

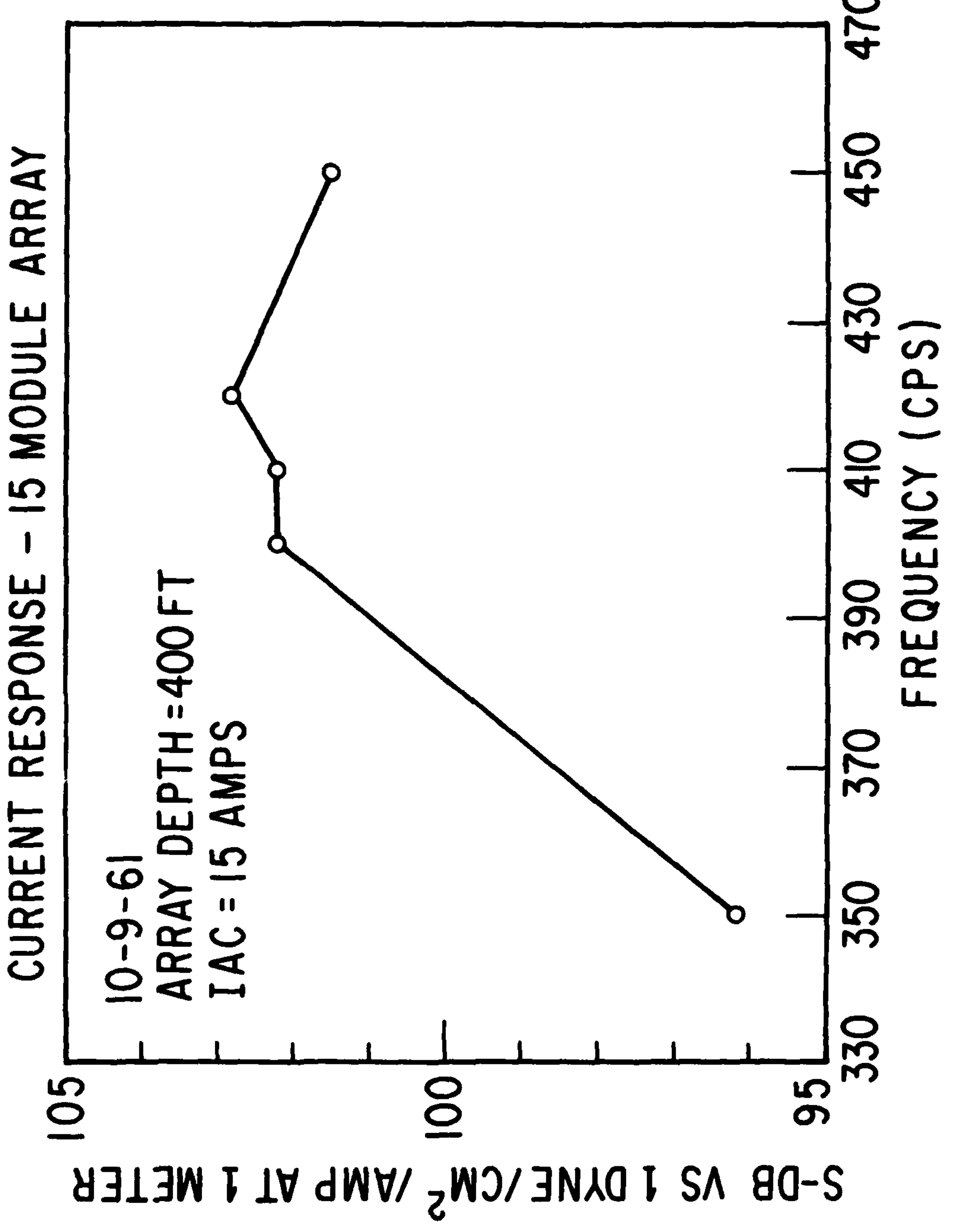
CURRENT RESPONSE – 15 MODULE ARRAY
10-9-61
ARRAY DEPTH = 400 FT
IAC = 15 AMPS
S-DB VS 1 DYNE/CM² /AMP AT 1 METER
105
100
95
330
350
370
390
410
430
450
470
FREQUENCY (CPS)

Figure 18 -

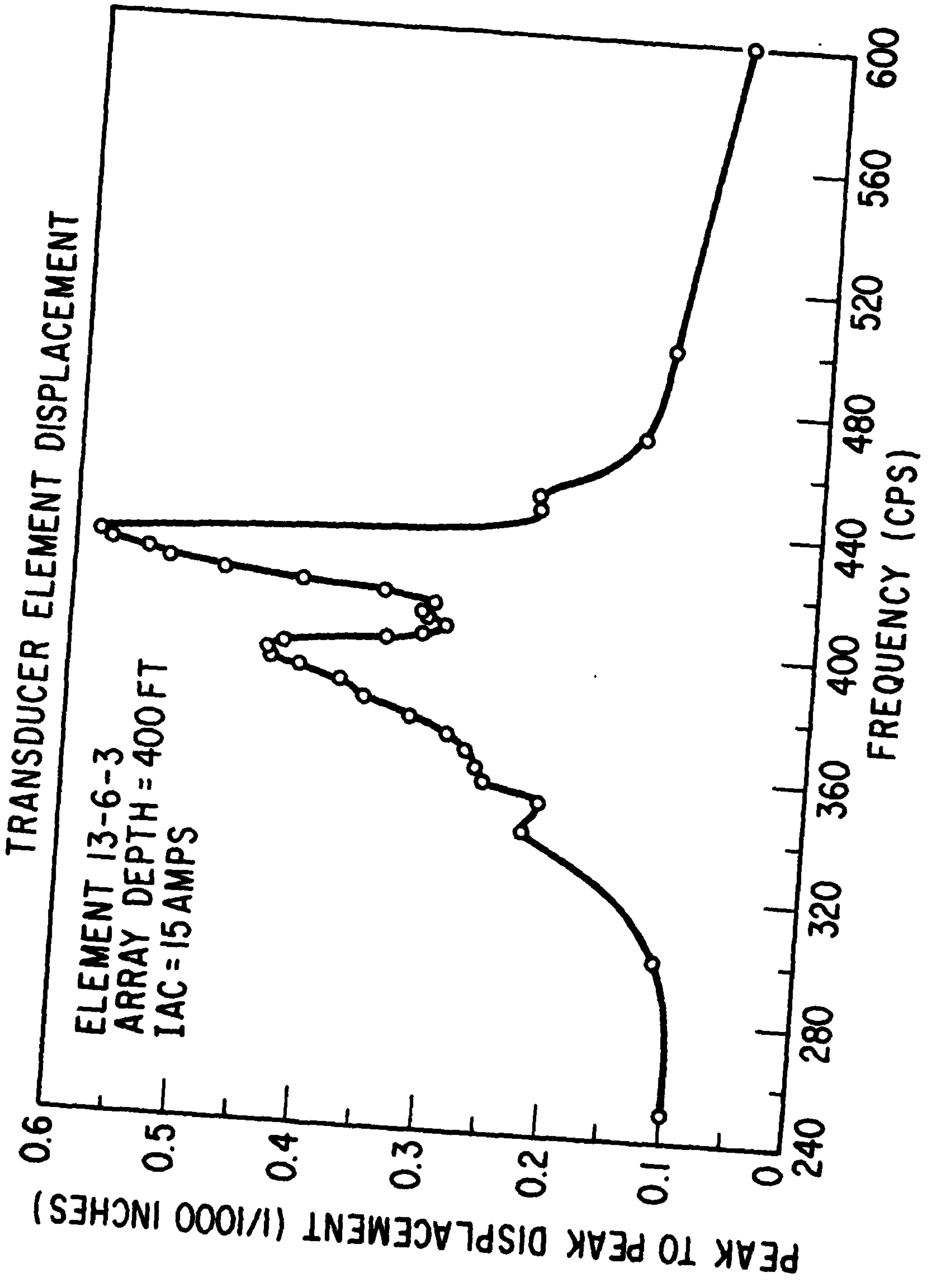

Figure 19 -
Frequency dependence of
transducer element displacement

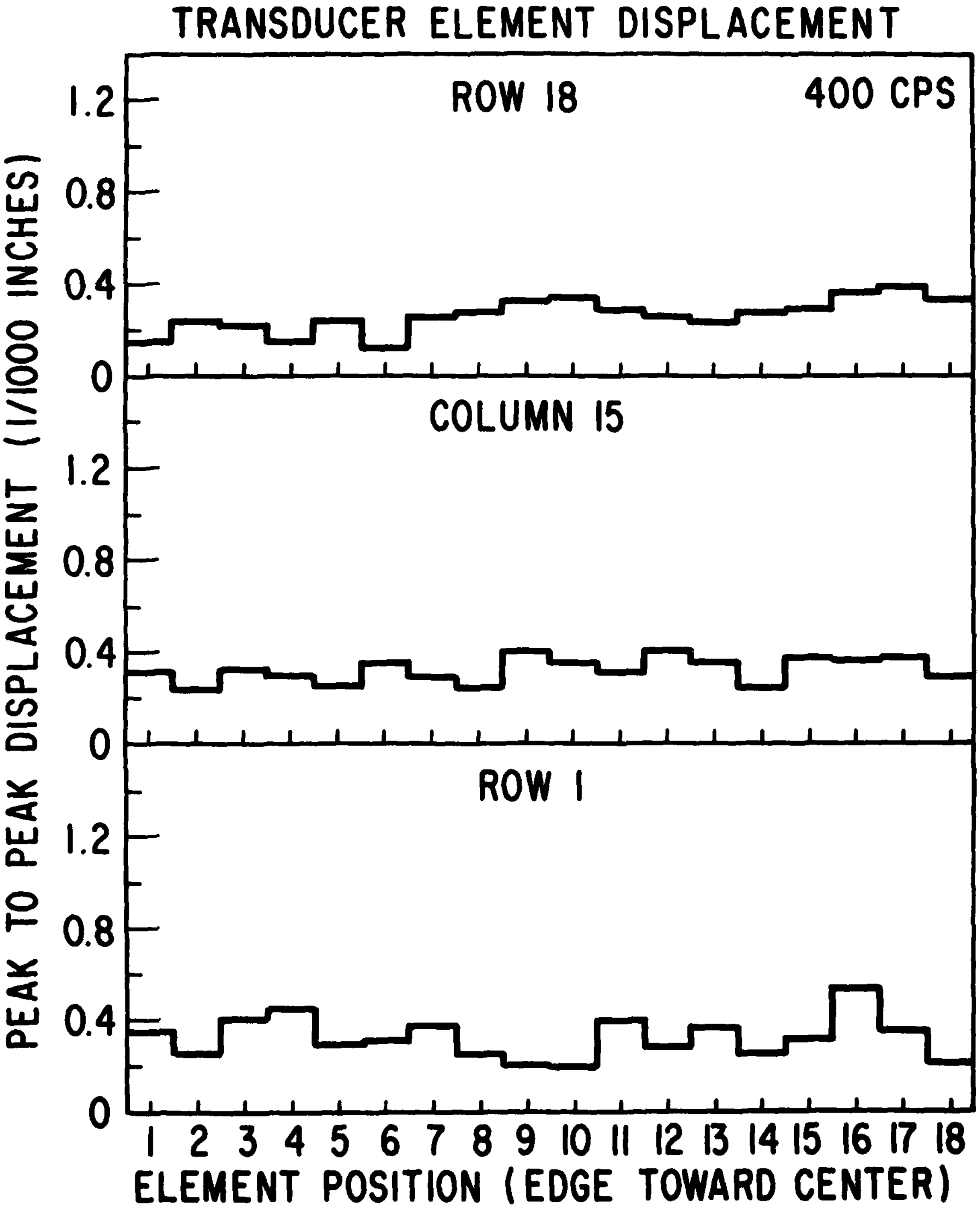

Figure 20a - position dependence of transducer element displacement

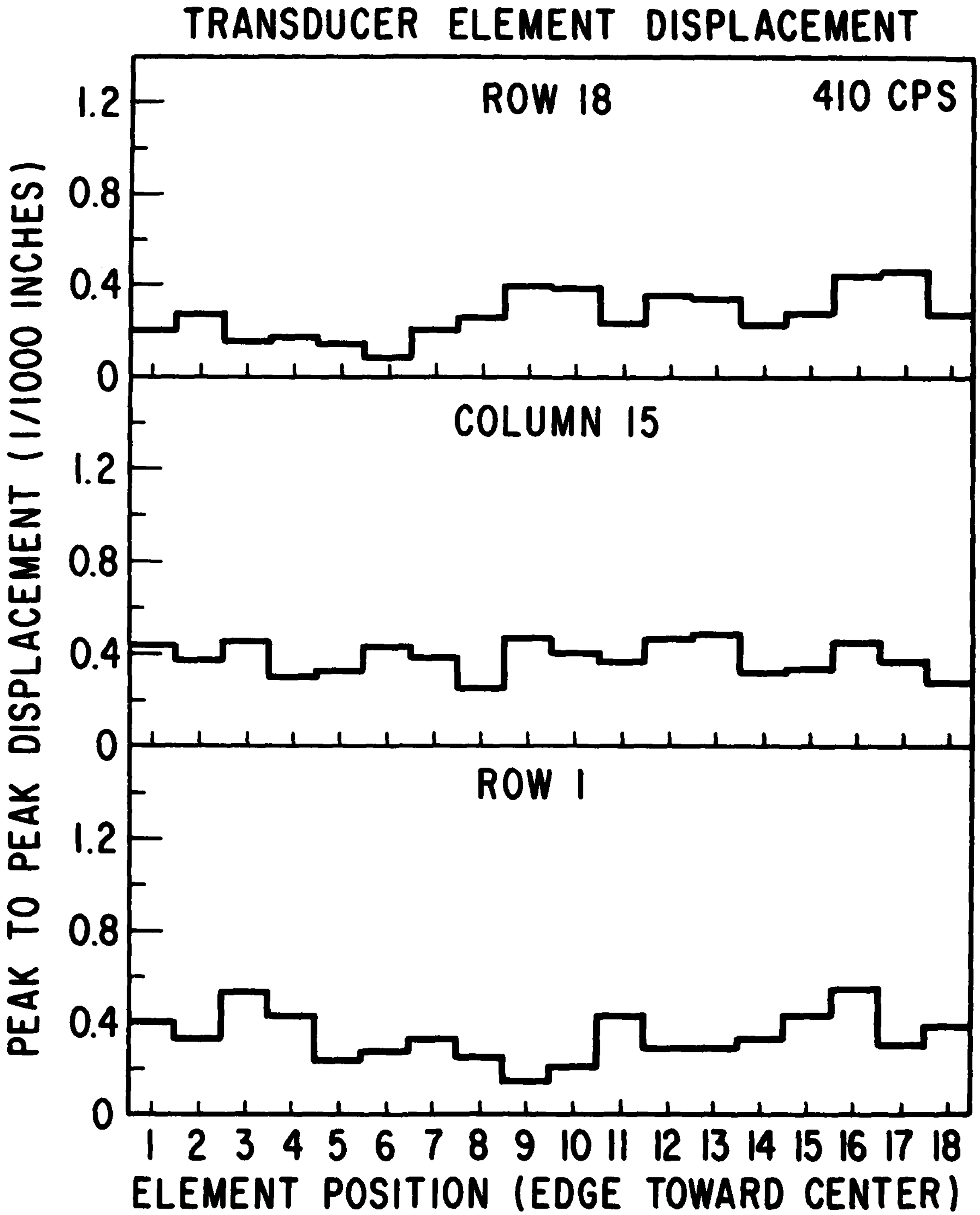

Figure 20b -position dependence of transducer element displacement

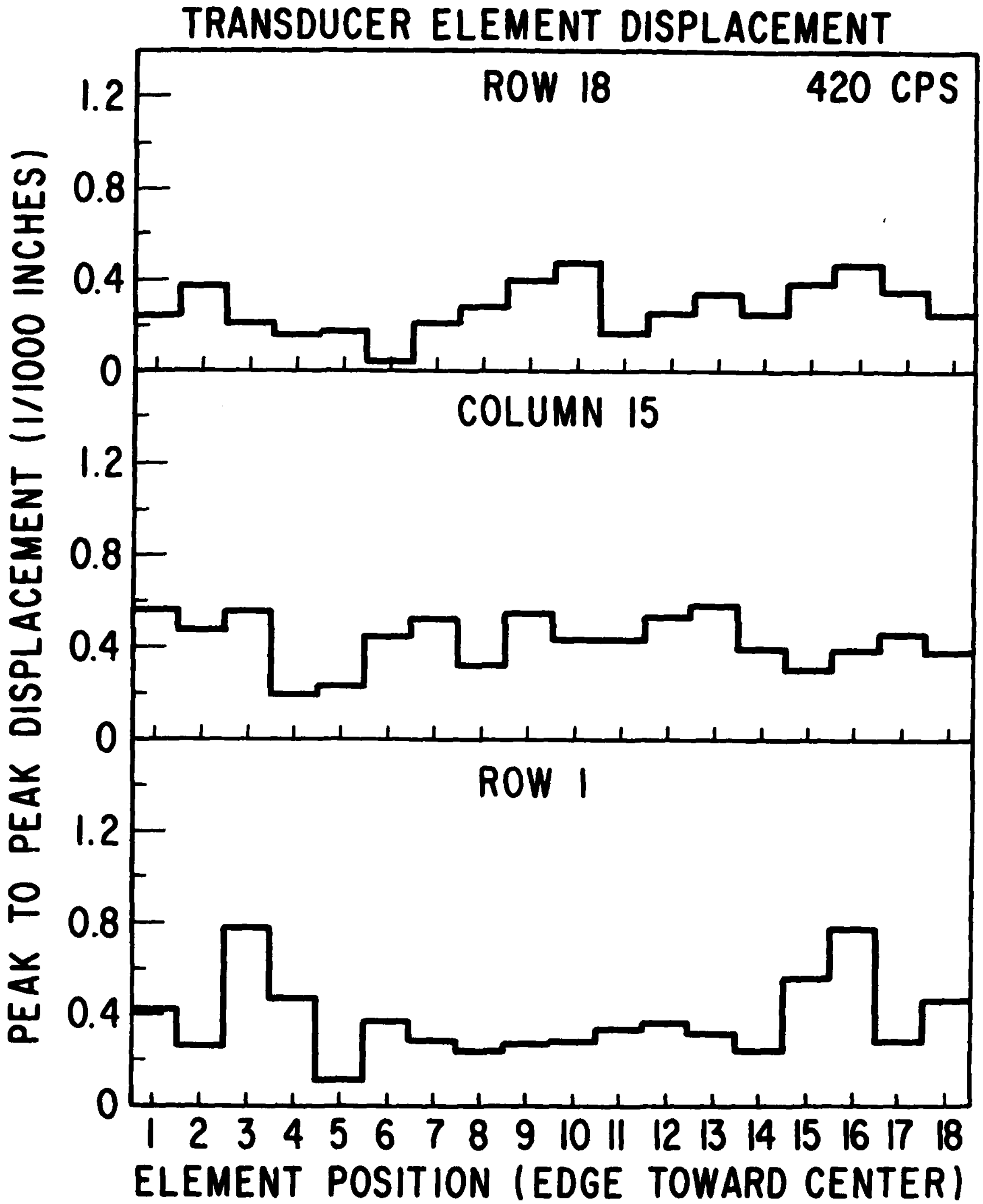

Figure 20c -position dependence of transducer element displacement

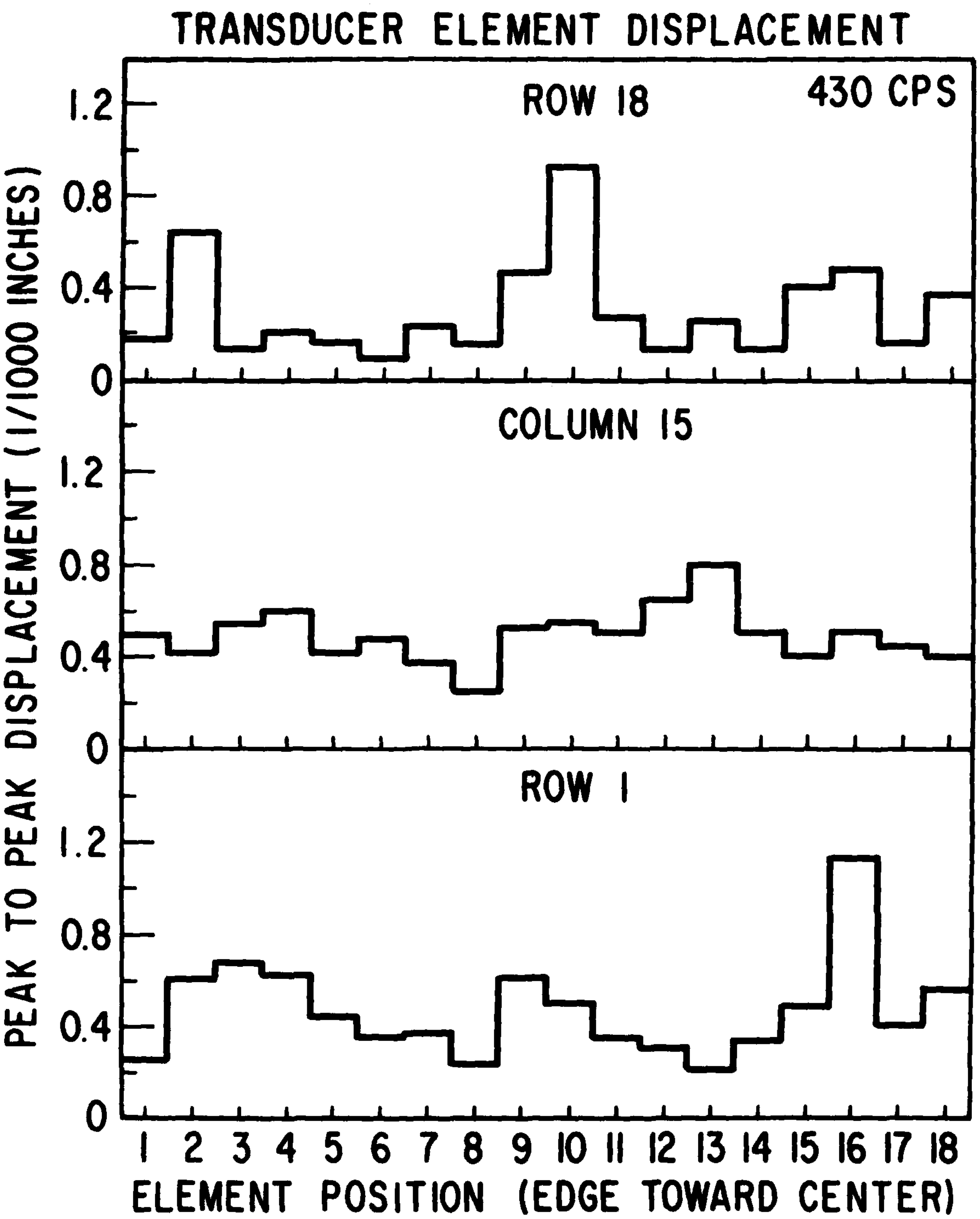

Figure 20d -position dependence of transducer element displacement

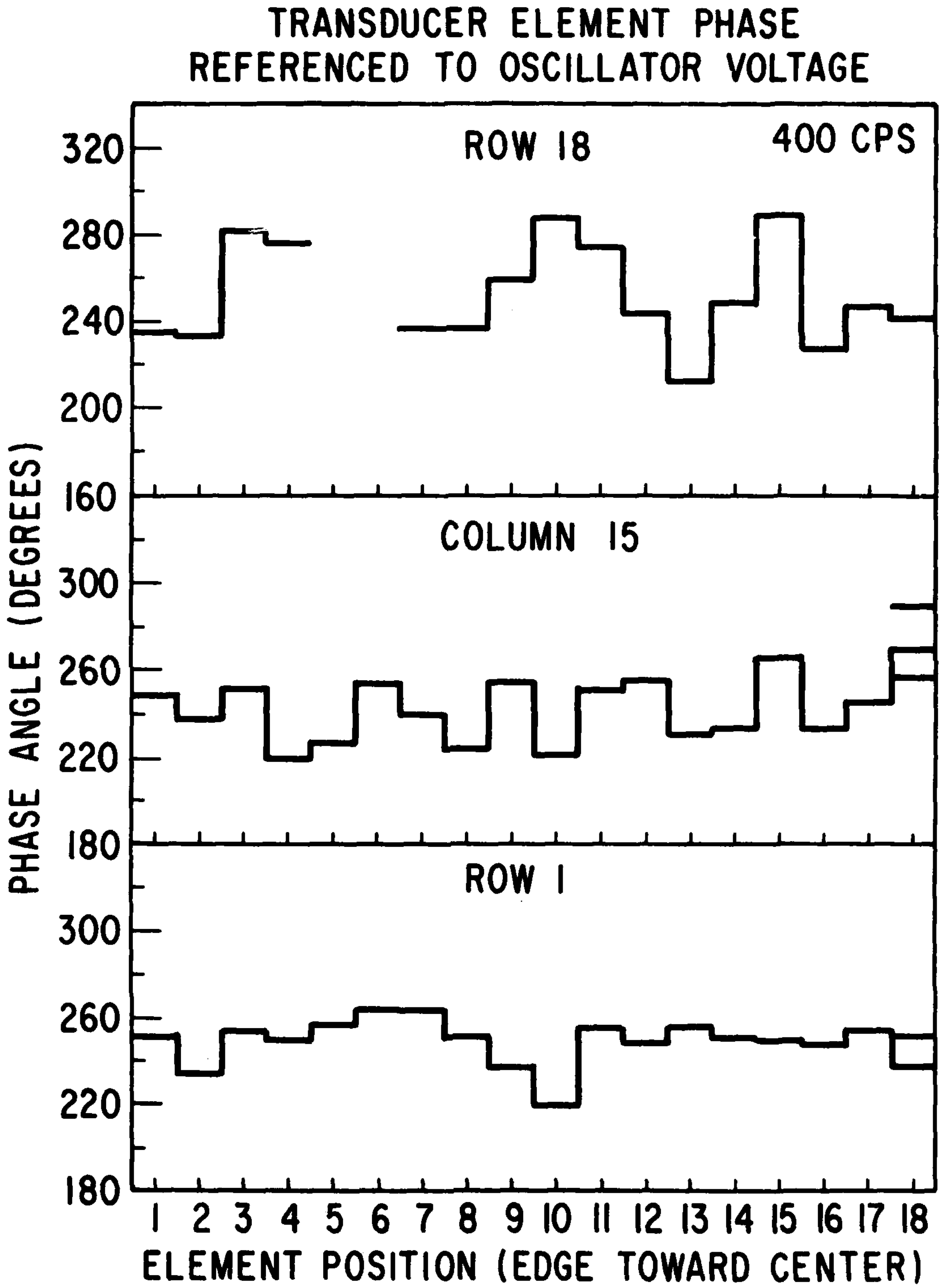

Figure 21a -position dependence of phase of transducer element displacement

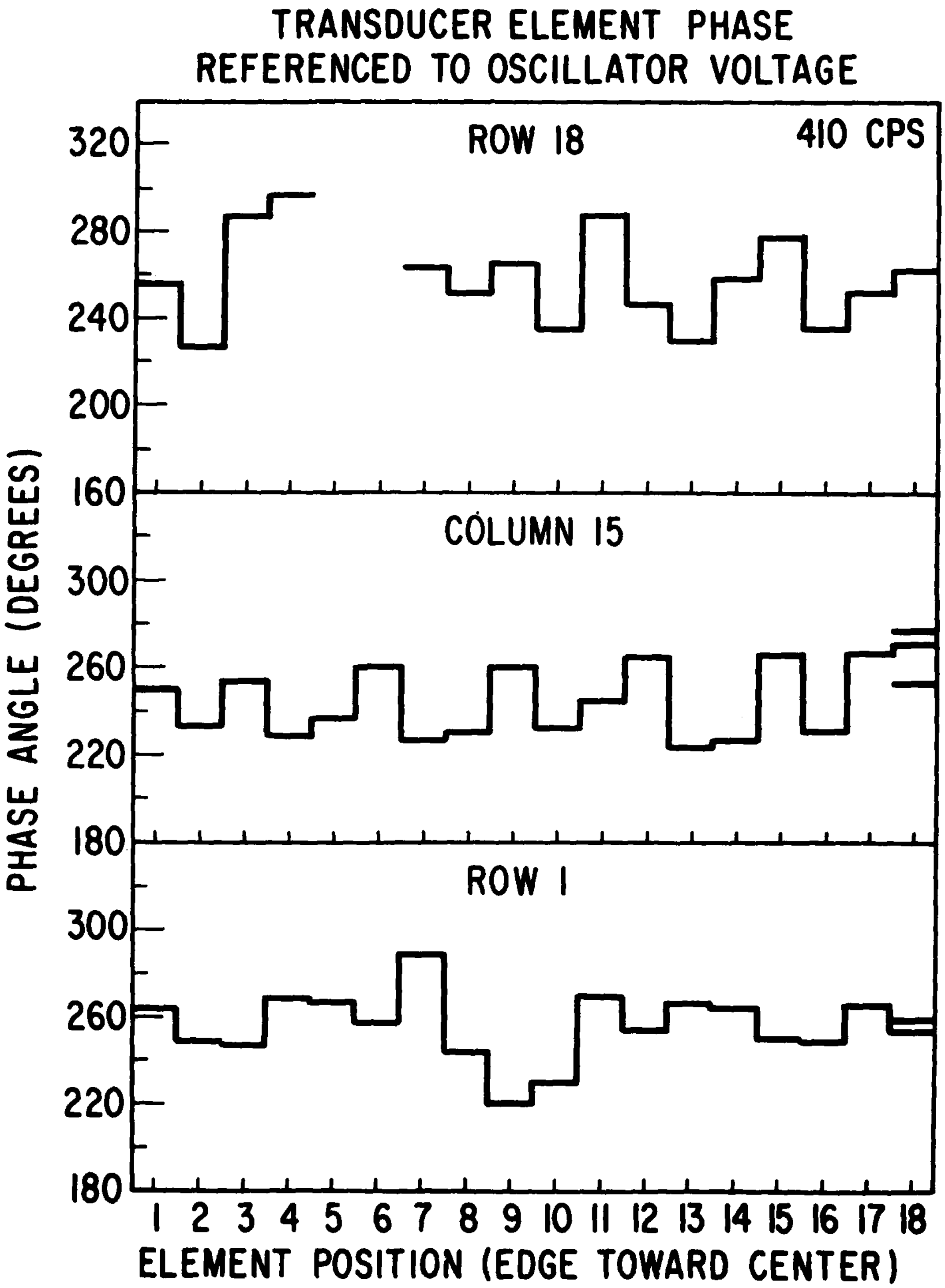

Figure 21b -position dependence of phase of transducer element displacement

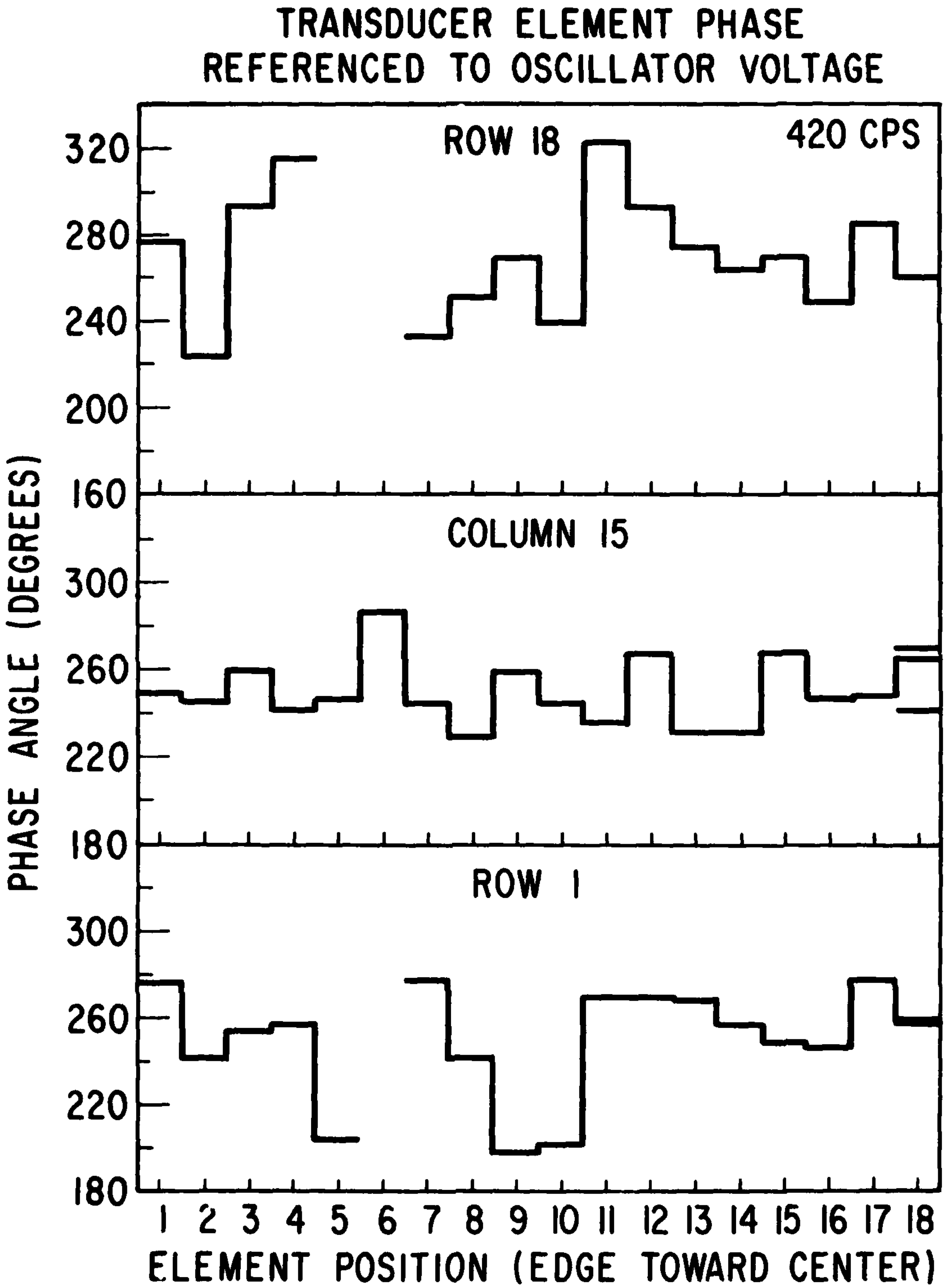

Figure 21c -position dependence of phase of transducer element displacement

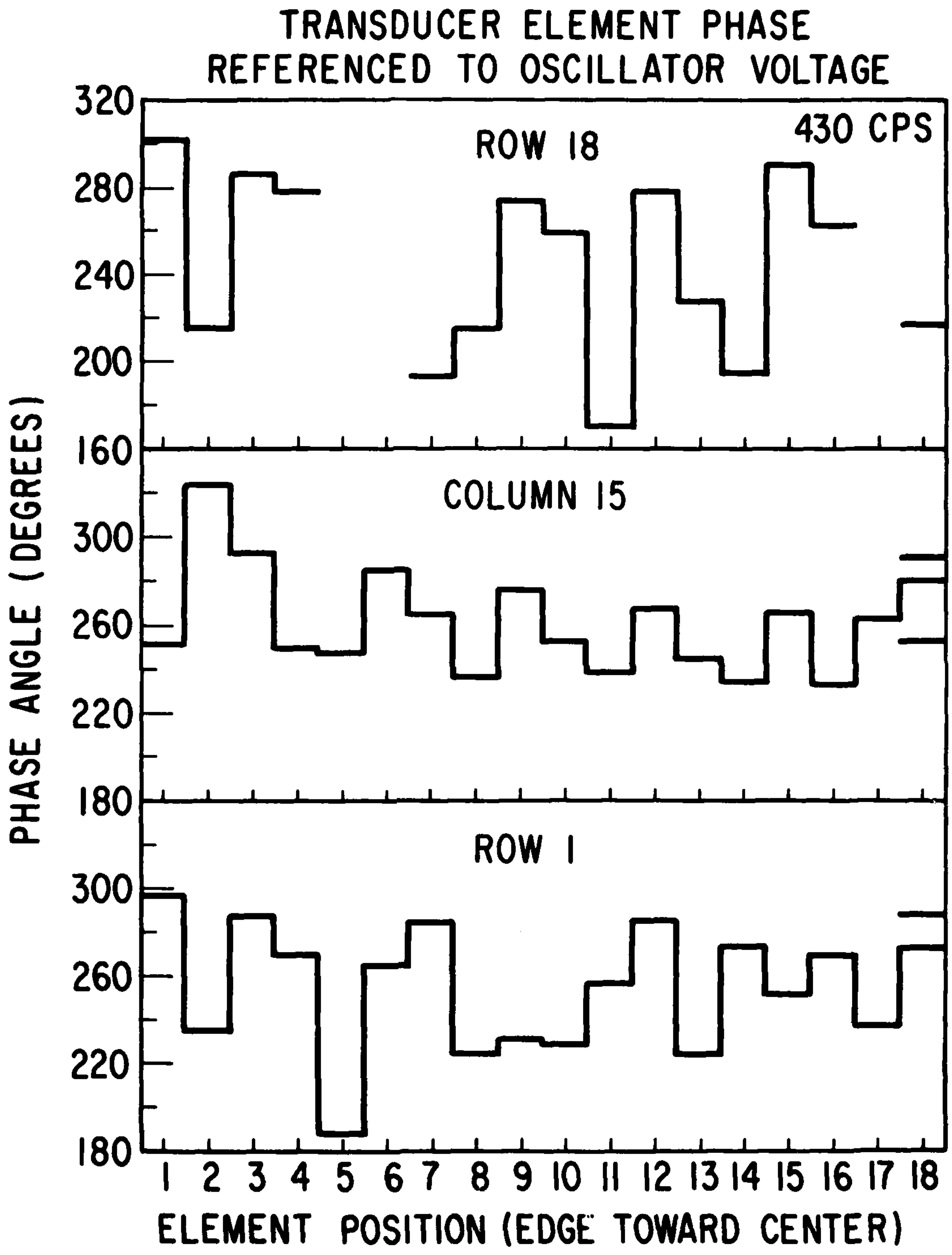

Figure 21d - position dependence of phase of transducer element displacement

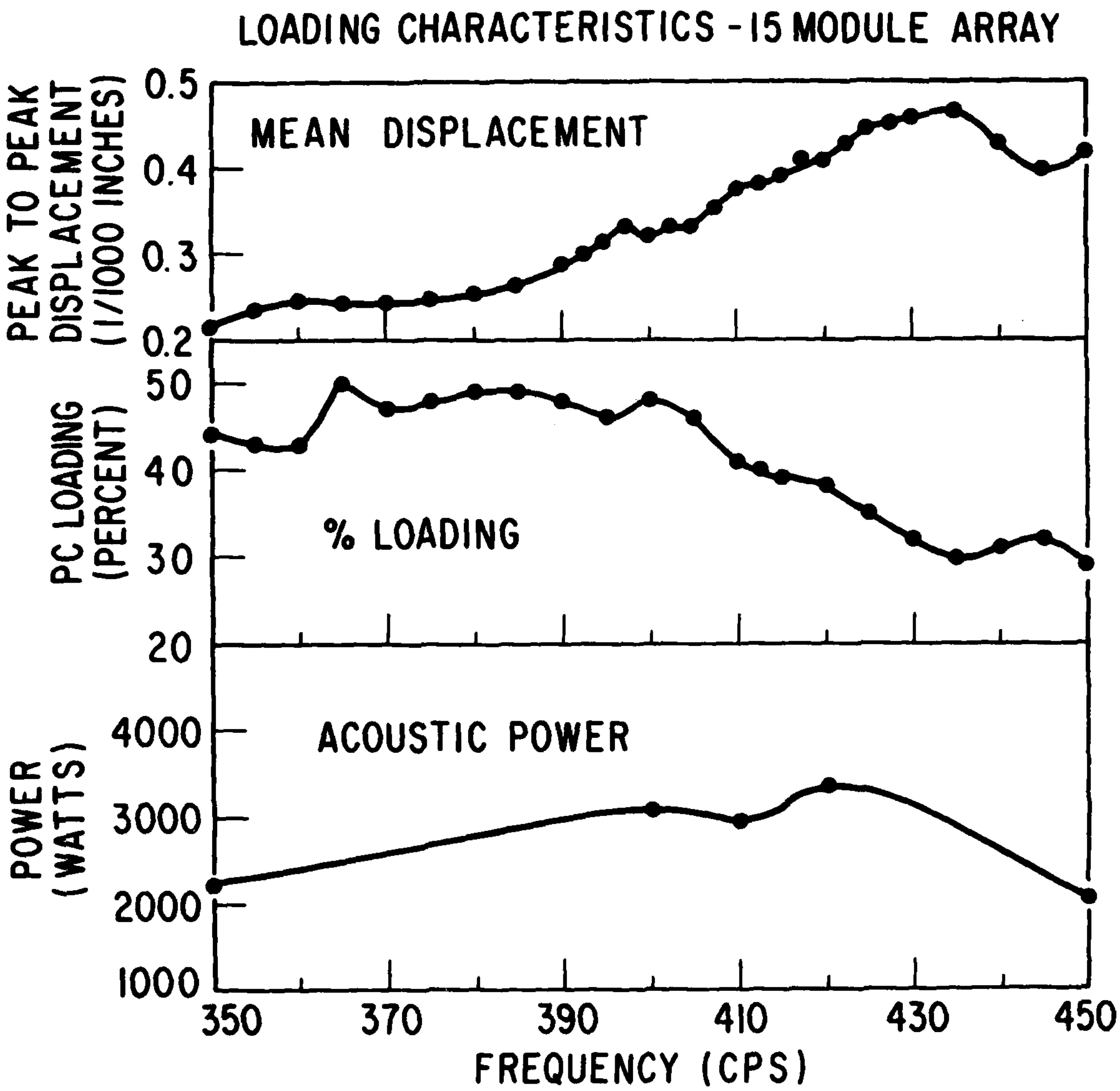

Figure 22 - RMS value of transducer element displacement

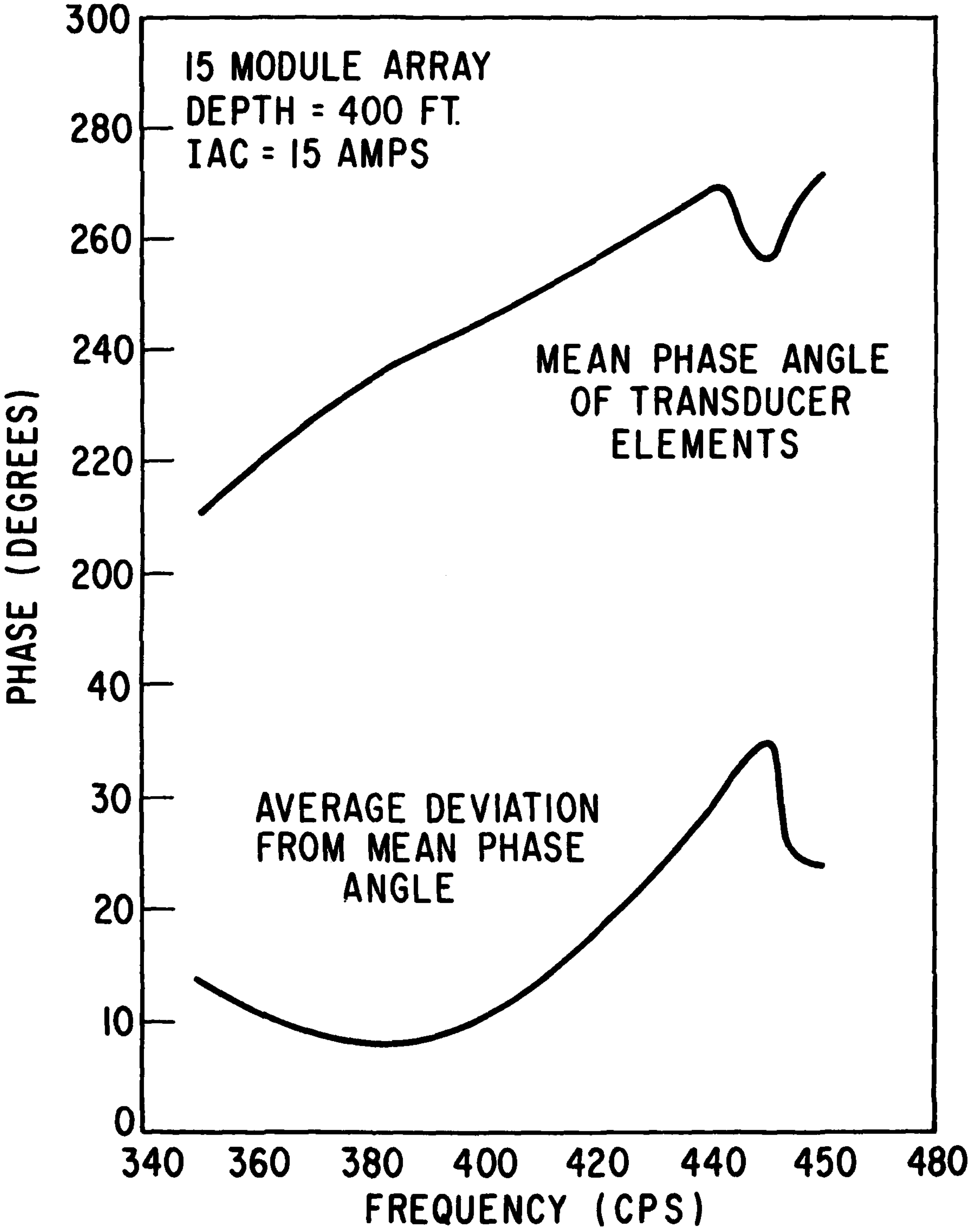

Figure 23 - Mean value of phase of transducer element displacement

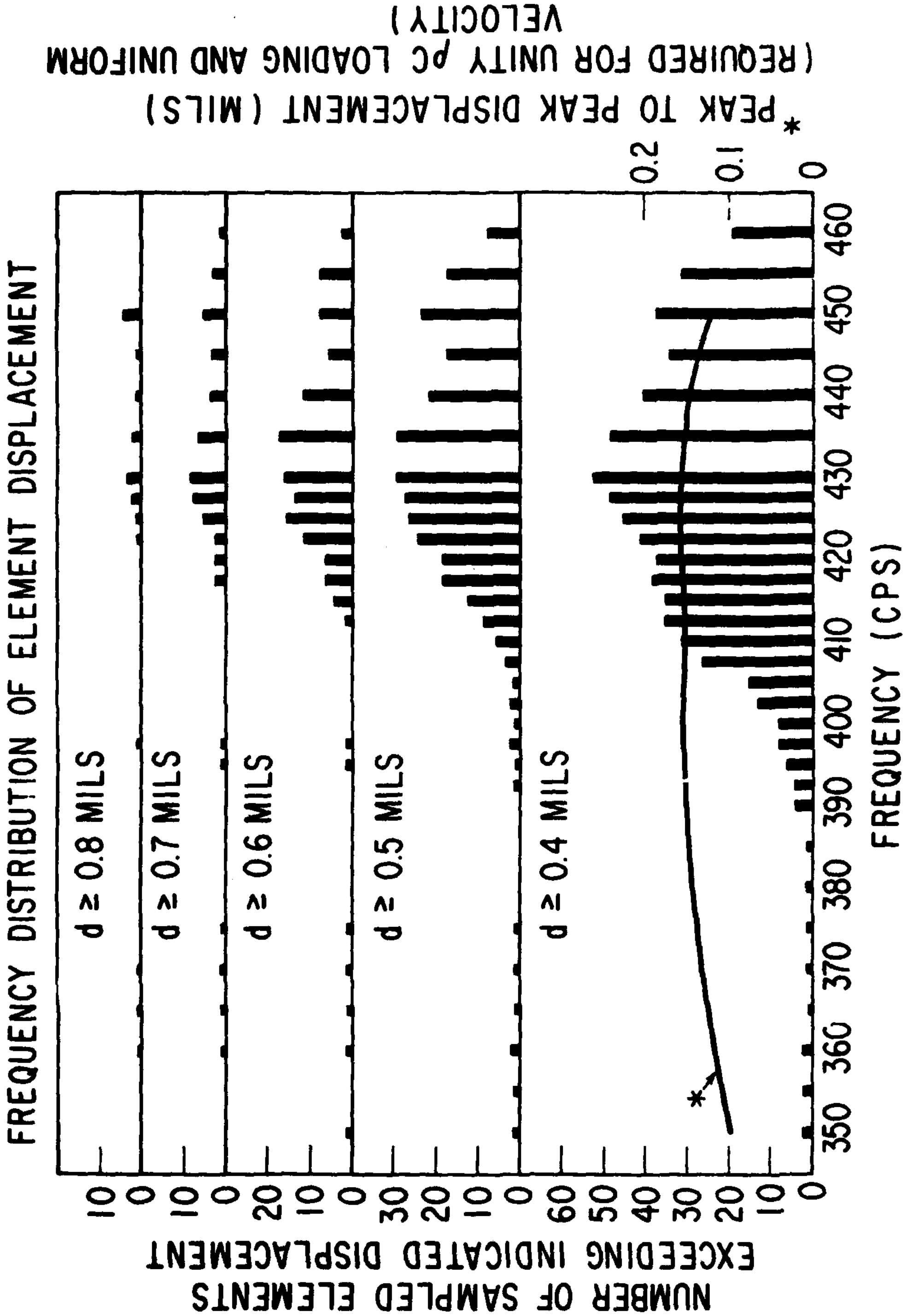

Figure 24 -
Frequency distribution of
transducer element displacement

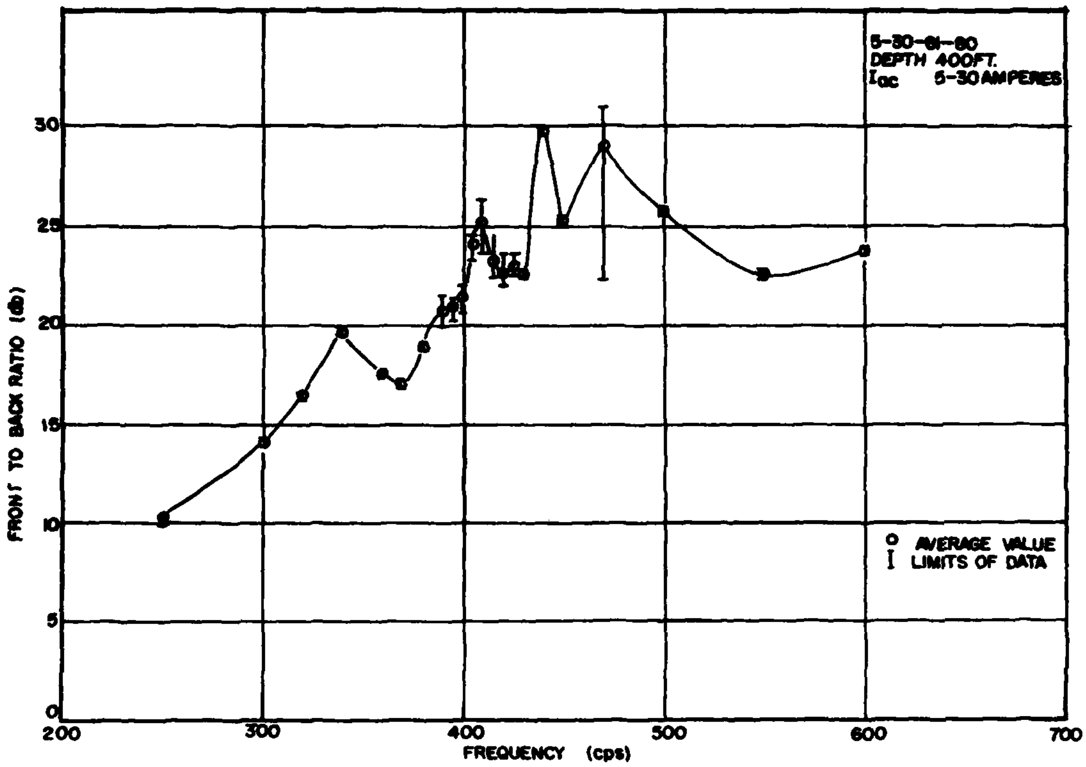

Figure 25 - Front to back discrimination

[redacted]

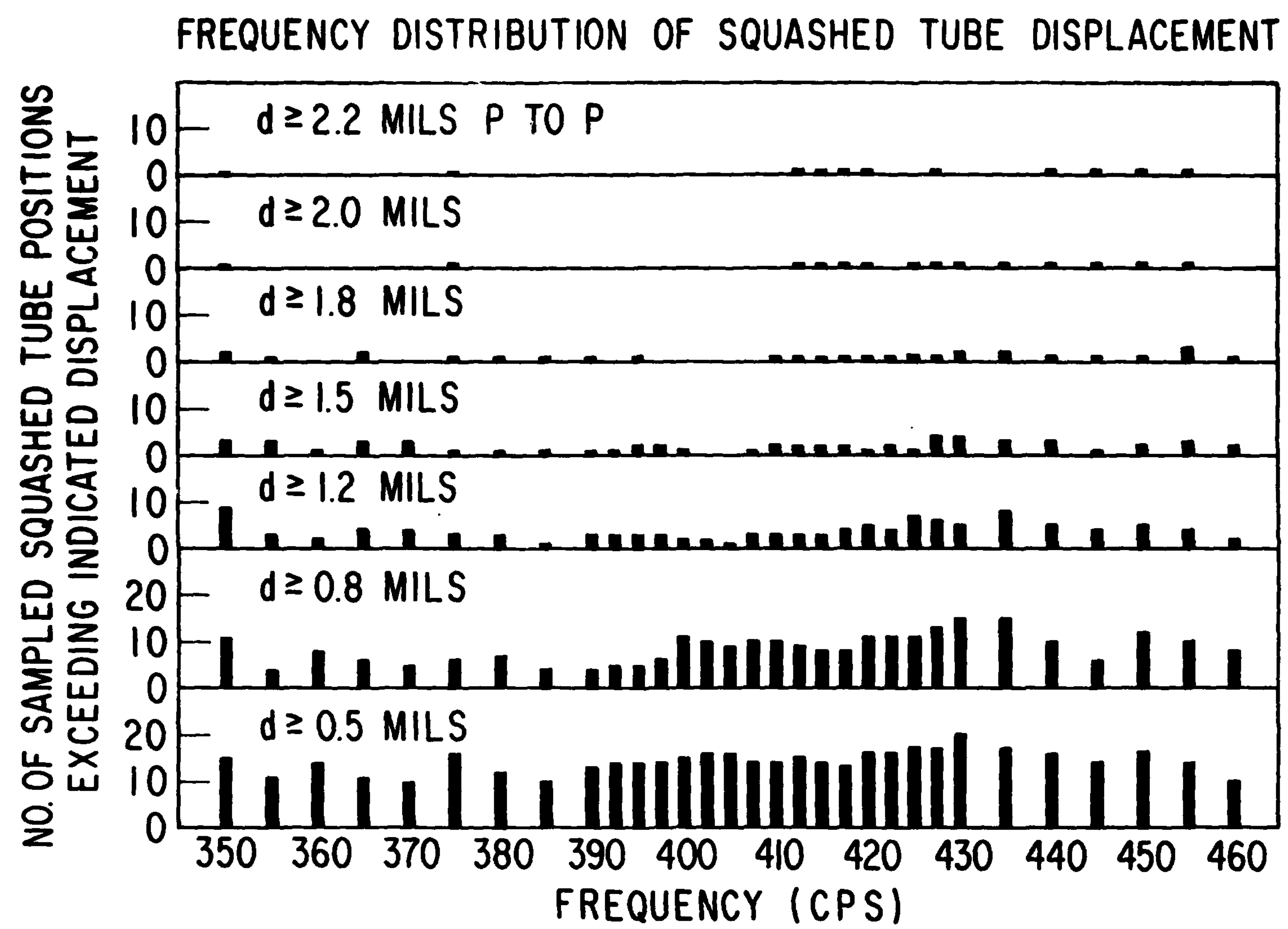

Figure 26 -
Frequency distribution of pressure release tube displacement

[redacted]L